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Cosmic Origins of the Elements
Is There a Tenth Planet?
Perfect Prospects for the Perseids

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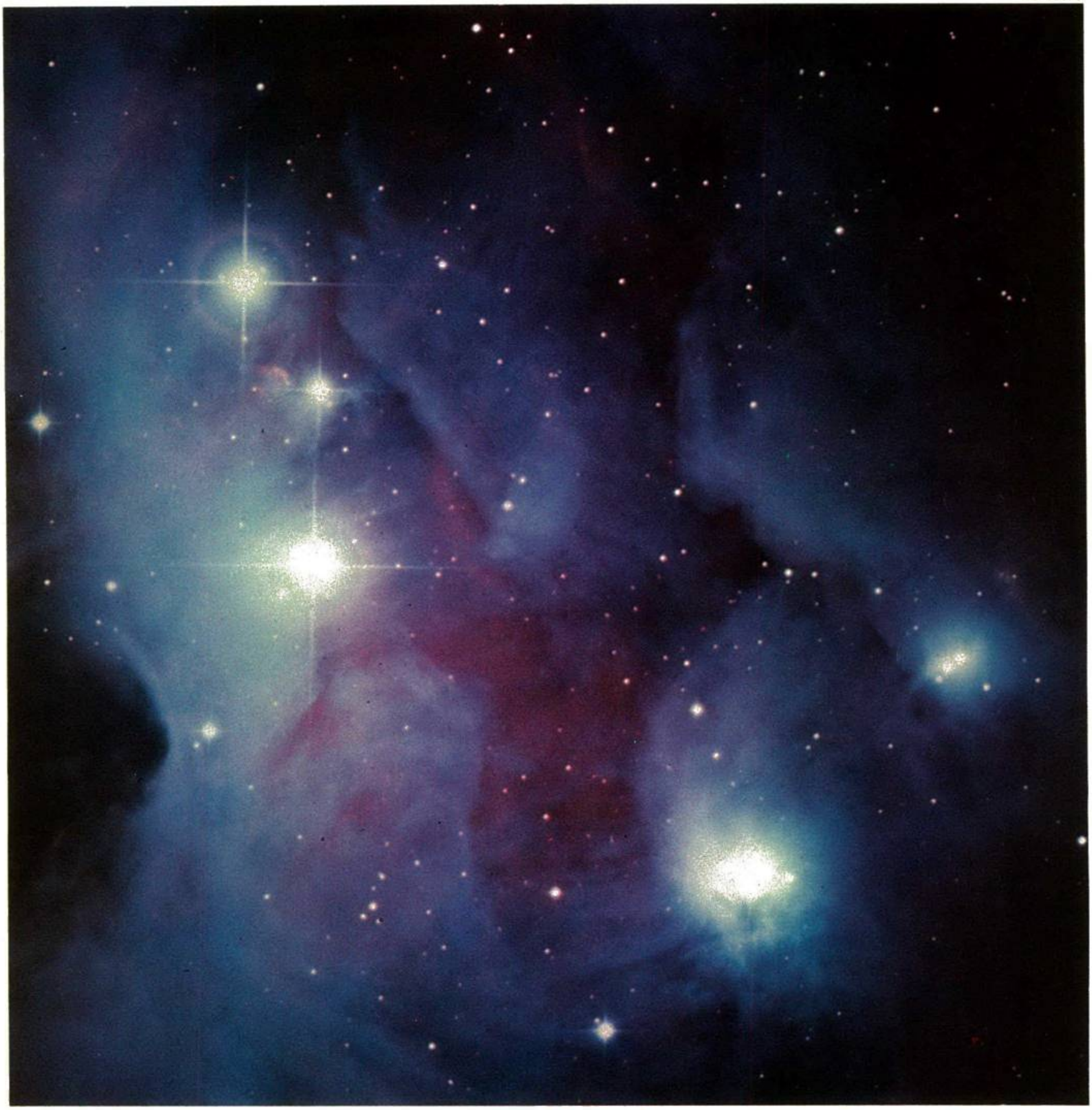
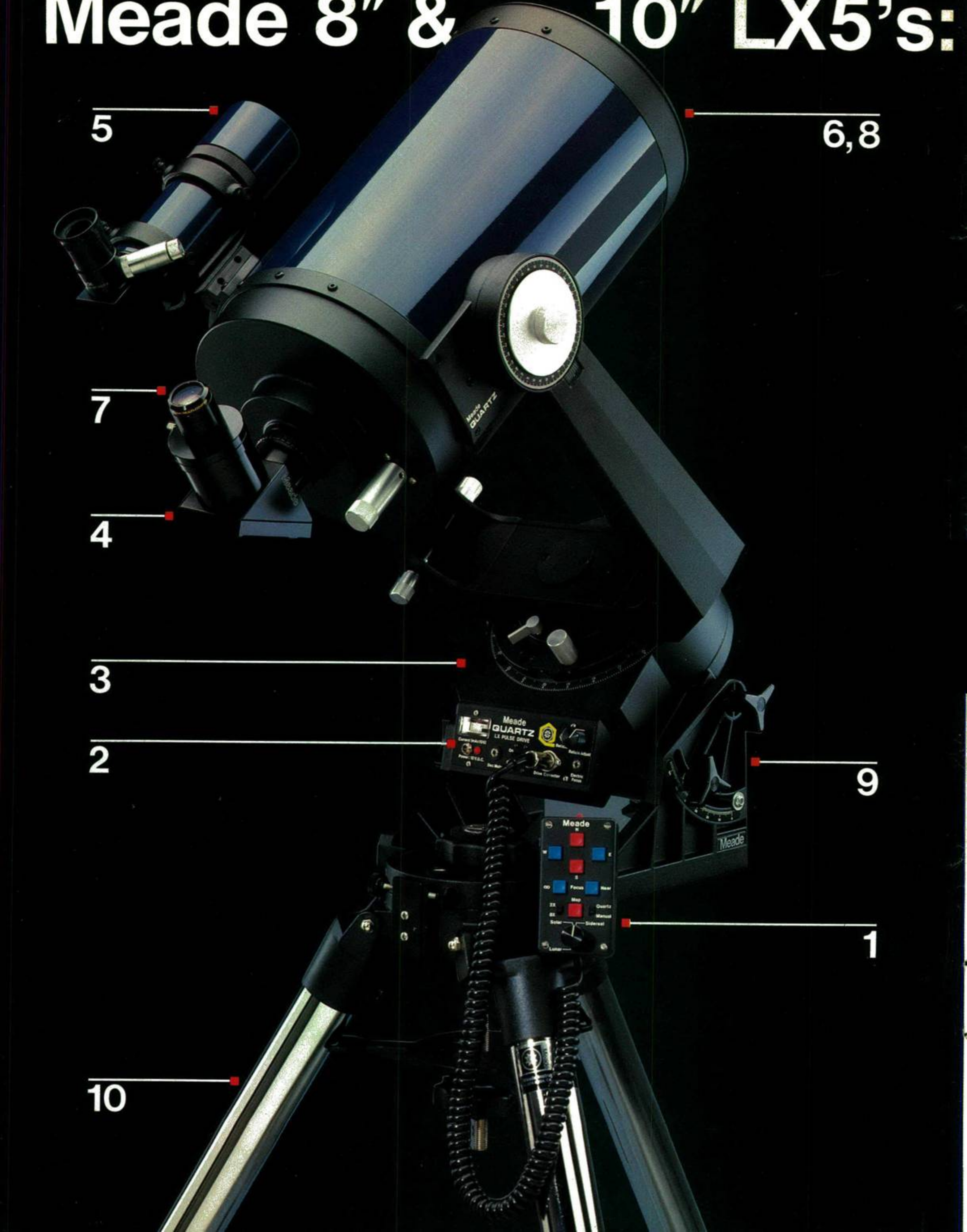


Birthplaces of the Heavy Elements

Meade® 8″ & 10″ LX5's: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Meade
QUARTZ
LX PULSE DRIVE
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Focus
Solar
Sidereal
Lunar
Quartz
Manual

Number *One* Worldwide.

See Why More Serious Amateurs Choose a Meade 8″ or 10″ LX5 Over Any Other Model or Brand!

1 Electronic Command Center: This *standard* feature puts virtually all telescope functions at your fingertips! Flip to the 8X Scanning Speed, and you're roving over the lunar surface at high speed, or touring the Orion Nebula, all at the touch of a button. Add the optional Declination motor for full dual-axis capability and you'll probably never use manual RA and Dec controls again! Use the 2X Correction Speed for micro-guiding corrections during astrophotography.

2 Power Panel Display: Monitor telescope operations at a glance. Panel modules include **(a) Ammeter** —Continuously displays electric current usage, to gauge battery life during power cell operation; **(b) North-South Switch** — Use your LX5 anywhere in the World! Simply flip the N-S switch to reverse drive direction for operation in the Southern hemisphere; **(c) 12 - Volts DC Power Inlet** — Each LX5 includes power cords for *3 types* of field operation: Directly from auto cigarette lighter plugs; directly from 115 v.AC house outlets; and from the Battery Pack, included, using AA-size batteries supplied by the user.

In addition, display panel output jacks are provided for the following optional systems: **Declination Motor**, for 2X/8X dual-axis operation; **#1200A Electric Focuser**, for ultraprecise microfocusing; and the **12mm Illuminated Reticle Eyepiece**, for guiding during astrophotography.

3 Quartz/Pulse Electronic Drive System: The most precise drive system available on any commercial telescope. Quartz microcircuitry drives the RA pulse motor and LX worm gear system to achieve true sidereal-rate tracking within ±.005% of the sidereal frequency. Or, switch to the "Manual" mode for variable Solar, Lunar, or Planetary tracking rates.

4 2″ Diagonal Mirror: Yes, a multi-coated 1/10-wave-flat Diagonal Mirror, accepting both 1¼″ and 2″ eyepieces, as *standard equipment!* Purchased separately, the 2″ Diagonal is normally a $300 optional accessory.

5 9 x 60mm Polar Illuminated Viewfinder: A super-large-aperture finder for easy location of faint objects; yields 44% brighter images than standard 50mm finders. Includes etched reticle scale for extremely accurate polar alignment.

6 Multi-Coated Optics Group: Standard on all 8″ and 10″ LX5's, the Multi-Coated Optics Group includes multi-layer coatings on the primary and secondary mirrors, as well as both sides of the correcting plate, for maximum light transmission and image brightness.

7 Super Plössl 26mm Eyepiece (1¼″ O.D.): Exquisite definition, resolution, and color correction from edge-to-edge of the visual field.

8 Certified, Laser-Tested, Diffraction-Limited Optics: Each Meade Schmidt-Cassegrain optical set is individually tested on a double-pass, laser autocollimator, to yield optical performance limited only by the laws of physics. There are no finer optics available.

9 Equatorial Wedge: With magnetic compass, latitude scale, bubble level, and micrometric azimuth control, for quick polar alignment of the telescope.

10 Variable-Height Field Tripod: The most stable in the industry, fully adjustable for comfortable observing, seated or standing.

Meade 8″ Model 2080/LX5 and 10″ Model 2120/LX5 are available *now* from your Meade dealer — at very competitive prices!

See for yourself why these are the ultimate instruments for *your* observing program — from the World's leading manufacturer of Schmidt-Cassegrain telescopes.

Meade MTS-SC8: 8″ Schmidt-Cassegrain

Looking for an 8″ Schmidt-Cassegrain with all of the optical performance of the LX5, but at a significantly lower price? Then the MTS-SC8 *(left)*, with special package features described below, is designed for you. Includes the exact same optical tube assembly as the 8″ LX5, but mounted on the Meade MTS fork mount with pier tripod, for rock-solid observing, visually or photographically. Feature-for-feature, the MTS-SC8 is far and away the finest value in 8″ Schmidt-Cassegrain telescopes:

☐ **8″ f/10 Schmidt-Cassegrain** diffraction-limited optical tube assembly. Available optionally with Multi-Coated Optics Group.

☐ **LX3 Quartz Electronic Drive System:** with ultra-precise LX worm gear drive, power panel, and quartz microelectronics.

☐ **AC or DC Operation:** Includes 25 ft. cords for operation from either 115v.AC or directly from 12v.DC auto cigarette lighter plugs.

☐ **Plug-in Drive Corrector Capability:** Just plug in the optional #36 Electronic Hand Controller *(shown)* for precise electronic corrections in RA.

☐ **Optional Electric Declination:** The #38M Declination Motor plugs into the power panel and is actuated from pushbuttons on the #36 Electronic Hand Controller.

Dealer Locations and Assistance — For your nearest Meade dealer location, or for free telescope information and assistance, call Meade Instruments toll-free from anywhere in the continental U.S.A. (except California): **1-800-854-7485.** From all other areas, including California, call direct (714) 556-2291.

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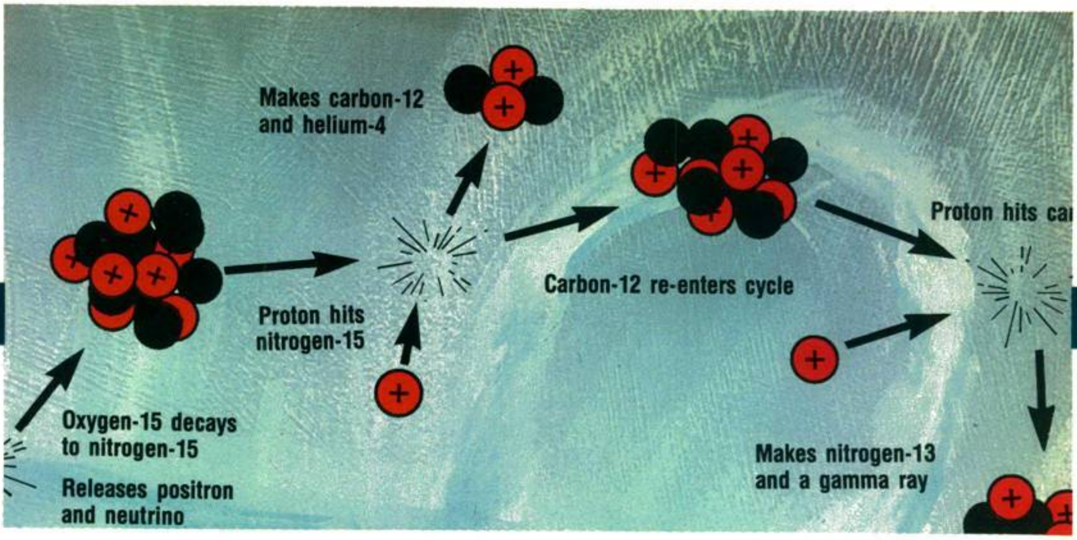
ON THE COVER: Chemical elements brewed in the nuclear fires of stars can create new stellar generations as in this star-formation region in Orion.


Makes carbon-12
and helium-4
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nitrogen-15
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Oxygen-15 decays
to nitrogen-15
Releases positron
and neutrino
Makes nitrogen-13
and a gamma ray
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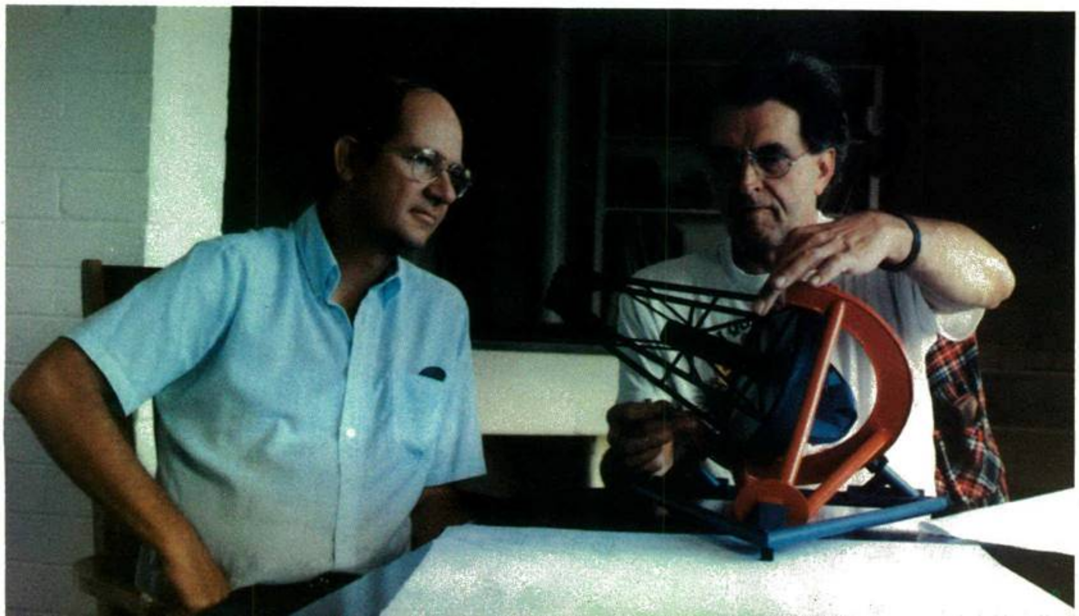
NUCLEAR CHAIN REACTIONS make chemical elements as they keep stars shining (page 18).

A PERSEID METEOR streaks into the head of Draco (page 78).



"SMART" TELESCOPES are changing how astronomers work (page 42).

ASTRONOMY®

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Behind the Scenes

LIVING WITH UNCERTAINTY

Uncertainty is inescapable in astronomy. A case in point is Planet X, a hypothetical body created to explain otherwise unexplained discrepancies in the orbits of Uranus and Neptune, discrepancies that had been attributed to Pluto until Pluto turned out to be too small to explain them. Is there a Planet X? We don't know.

The case of Planet X puts astronomers on the spot. Are the observations they're working with sufficiently good? Why don't we see perturbations in *Pioneer 10*'s trajectory? Should we even be searching for a Planet X? A decade or a century from now we may have answers. Today, without the benefit of hindsight, we have no answers.

Does the fact that great uncertainties remain mean that astronomy is somehow deficient? Does not knowing everything about the nature and state of the universe mean we cannot trust what astronomers say? Not at all. The wonder is really that we know as much as we do about objects so unimaginably remote. After all, there's plenty of uncertainty left in the most mundane of terrestrial pursuits — the proper time to plant tulips, current tax law, or the best way to restore antiques.

At its core, astronomy is a human activity, something people do, whether driven by curiosity, ambition, or passion. In their pursuit of astronomy, astronomers may exult over discoveries, squabble about who gets credit, mourn the loss of beloved theories, or worry about real or threatened cuts in funding. Overall, though, because astronomy is a science, it tends to be self-correcting, so errors and misconceptions are discovered and thrown out, while notions that give us deeper insight into the nature of the universe gain support and flourish.

But uncertainty remains. We must accept the fact that astronomers can't say how many planets orbit the Sun. We know of nine, and there may be more. That's what makes astronomy endlessly fascinating to me — that even as I write, what we know about the universe is growing and changing.

Despite deep uncertainties in what we know, though, the stars and planets remain a timeless and magnificent element in our lives. We can point our telescopes at the sky to gaze with wonder at the dim swirls of the nebulae and — without having all the answers — still feel a thrill.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

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Letters

Televising Mars

In addition to the ideas presented in Behind the Scenes (May 1988) about popularizing the current apparition of Mars, I'd like to encourage the use of television. Mars is one of the few objects that can be seen easily with conventional home television cameras. Using television at public star parties is advantageous because many people can't cope with eyepieces and a lot of people can watch the screen at the same time.

While many television stations will not accept tapes from home recorders, my astronomy club has often allowed the local newspeople to mount their minicameras on the club's telescopes, which results in quite a bit of publicity. Most newscasters will jump at the chance to show Mars close-up during the apparition, but arrangements should be made well in advance of the event to make sure their cameras fit on your telescope. — *Peter L. Manly, Tempe, Arizona*

The Threat of 'Security' Lamps

I have seen the problems of high-pressure sodium lighting aired many times, but the situation is not hopeless for the backyard observer watching the planets or deep-sky objects with a filter.

However, a greater threat is on the rise: the rapid spread of so-called "security lamps" in neighbors' backyards. The glare can be so great that even planetary observing can be hindered. Recently two of my neighbors installed such lights. When combined with a badly placed street light, these lamps make observing from a back garden well-nigh impossible, even if one of the lights is turned off. As a result, my observing now has to be done — inconveniently — elsewhere. — *Gareth A. Jarrett, Rochester, Kent, England*

Preserving the Stars for Our Children

After reading Gary Williams' "The Joys of Rural Stargazing" (Forum, May 1988) and seeing notices of upcoming Astronomy Day celebrations, I realized that we amateur astronomers need to pursue a much broader goal. Just as the Sierra Club is struggling to save our national forests, so too must we act to preserve what remains of our dark skies.

A century ago most citizens could go outside and, by shielding their eyes from local lighting, see the Milky Way above. Today only those who live in rural areas can still see the Milky Way from their homes. It is ironic that in what we call the scientific age a knowledge of the oldest science is denied to most people.

If we cannot halt the overuse and misuse of outdoor lighting, our children and grandchildren will be unable to expe-

Take yourself on "an automated self-guided tour of the universe" with the Meade® CAT.™

". . . so quick you really *can* observe 100 objects an hour, as the ads say . . . If you prefer to spend your time observing deep-sky sights rather than hunting for them, then the CAT is ideal."— *Sky & Telescope*, November, 1987.

". . . the CAT is a true time saver, a device that can show hundreds of objects per night . . . the payoff is an automated, self-guided tour of the universe." — *Astronomy*, December, 1987.

What it is: The Meade CAT ("Computer Aided Telescope") system is a revolutionary telescope accessory that leads Schmidt-Cassegrain telescopes from object to object, in *seconds.* The graphic display on the CAT's console enables the observer to locate *any object in the CAT's 8,199-object memory within, literally, 5 to 10 seconds or less.*

How it works: Included with the CAT are 2 precision optical encoders that mount on the telescope and sense the telescope's position in RA and Dec; the encoders permit the location of even the most obscure objects with 25 times the precision of standard setting circles. Using the CAT's large, red-illuminated crossline display, the observer manually moves the telescope to the position dictated by the crosslines. The CAT unerringly positions the desired object precisely in the center of the telescopic field. In addition, digital readouts on the display console continuously display R.A. and Declination.

Object Database: Included within the CAT's computer memory database are the positions of 8,199 objects — *virtually every object of interest in the entire celestial sphere, North and South:*

☐ **7,840 Deep-Space Objects,** including all 110 Messier objects, plus 7,730 other objects contained in the Computerized New General Catalog (CNGC) — galaxies, nebulae, star clusters, objects of every description in the sky.

☐ **351 Bright Stars,** used primarily as CAT reference objects, including 100 interesting double and multiple stars.

☐ **8 Major Planets:** The positions of all 8 major planets are included in the CAT's memory, a feature not available on any other computerized telescope system. In seconds you can locate Mercury, even in bright twilight; observe Uranus and Neptune; or photograph the day-to-day motion of 14th-magnitude Pluto. The CAT enables the positioning of these and the other major planets in the center of the field, *easily and rapidly.*

The Meade CAT attaches in minutes to Meade and other brands of Schmidt-Cassegrain telescopes and may be adapted by the user to other types of telescopes as well.

Models and Pricing

CAT #9000: for all Meade 2080 models	**$1495**
CAT #9001: for all Meade 2120 models	**1495**
CAT #9003: for C8 fork-mounted models	**1495**
CAT #9005: for C11	**1495**

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The CAT, shown on a Meade Model 2080/LX5.

NEW!
Digital Setting Circles for your Schmidt-Cassegrain!

Meade
Init
Mode
Set
RA 22:36
DEC -26.5

Meade Digital Setting Circles utilize the high-technology of the CAT, but without the CAT's massive object database and other features, at a significantly lower price. Compare these specifications:

4 Operating Modes: Depress the "Mode" button sequentially and obtain:

Mode 1: reads out the Local Time and Sidereal Time on the 2 readout registers.
Mode 2: reads telescope Right Ascension and Declination. R.A. reads out to a precision of 1-min., Dec to 0.1°.
Mode 3: enables a digital timer for timing astrophoto exposures.
Mode 4: turns both registers "Off."

Optical Encoders: Meade Digital Setting Circles utilize Hewlett-Packard optical encoders for the highest level of precision and sensitivity. The encoders attach in minutes to the polar and Dec. axes. The readout unit mounts onto the telescope's rear cell, where it is *continuously visible from the eyepiece observing position as you move from object to object.*

Models and Pricing

DSC #9060: for all Meade 2080 models	**$495**
DSC #9061: for all Meade 2120 models	**495**
DSC #9063: for C8 fork-mounted models	**495**
DSC #9065: for C11	**495**

Warranty: Every Meade CAT and DSC unit is covered by a 3-year warranty on parts and labor.

For further information: Send for your free copy of Meade Bulletin CAT/DSC, or send $3.00 for the complete Meade **General Catalog #88C.** The 75-page CAT Instruction Manual is available at $5.00.

Better still, call or visit your authorized Meade dealer; he'll be glad to answer any questions on the Meade CAT and DSC's — two of the most exciting and revolutionary telescope accessories ever developed.

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rience the grandeur of the universe without traveling to remote areas of the world. Our mission must be to convince citizens of this and other countries that the starry heavens are worth saving. — *Leland A. Dolan, Houston, Texas*

Ownership of the Solar System

I read the interview with Robert M. Powers and the excerpt from Powers' book (Forum, April 1988) with great interest. The questions raised in the excerpt about the ownership of celestial bodies are currently being discussed by space lawyers, and I am working on a book about the legal implications of planetary settlements.

Some of Mr. Powers' fears seem unnecessary. Stations are owned by the launching state even if lunar or Martian resources are used. Materials needed to run the station will be owned by whoever owns the station, but the principle of nonappropriation is only valid for resources *in place*.

On the other hand, territorial claims on Mars are not possible. It is a binding rule of customary international law that celestial bodies are not subject to national appropriation. The United States would have no rights of sovereignty on the Moon even without any Outer Space or Moon Treaty. Celestial bodies are *res communis omnium* as is the air you are breathing: anyone may use them, but nobody can claim exclusive rights to them. — *Elmar Vitt, Cologne, West Germany*

Lack of Support for Space

The most interesting aspect of the responses to ASTRONOMY's reader poll about space policy was overlooked in your analysis ("Shaping America's Future in Space," May 1988). The fact that only 2,250 readers responded to the survey makes a sad statement.

How can we expect government policymakers and the general public to take an interest in future space exploration when 98 percent of your own readers did not participate in the opinion poll? — *Paul A. McCredie, Oklahoma City, Oklahoma*

Correction

The price of the SureSharp camera focuser was incorrectly given in a review published in the June 1988 issue. The correct price is $119.

ASTRONOMY welcomes comments, suggestions, corrections, and additional information on articles and astronomy. Send your letters to: ASTRONOMY Letters, 1027 North 7th Street, Milwaukee, WI 53233. Letters may be edited for length and clarity. ☐

Viewpoint

NASA'S SPACE SCIENCE STRATEGY

At the dawn of the 21st Century, we will have successfully pushed back the frontiers of space to further explore and understand the universe in which we live.

The four Great Observatories — the Hubble Space Telescope, the Gamma Ray Observatory, the Advanced X-Ray Astrophysics Facility, and the Space Infrared Telescope Facility — will be operating together to observe the universe across the entire electromagnetic spectrum.

With the information these observatories reveal to us, we will gain a deeper understanding of our place in the universe. Many totally unexpected scientific discoveries will be made; nature, unfettered by the limitations of human imagination, will continue to surprise us.

Our way of thinking about our uniqueness in the universe will change. We will have good estimates of how many stars have planetary systems and we will have an image of at least one planet in orbit around a star other than our Sun.

By the 21st century many totally unexpected scientific discoveries will be made. Nature will continue to surprise us.

The strategy for realizing this vision is necessarily ambitious, yet it is firmly tempered to be realistic enough to succeed. The first step in determining mission priorities and sequence is the establishment of a realistic budget level. If the growth in the total NASA budget continues over the next several years at its currently planned rate, then initiating major missions at a rate of nearly one per year will be possible. In some years, however, the initiation of moderate missions rather than major missions may be dictated.

Our plan makes a bold statement that the United States will pursue world leadership in space science in 1989 through an initiative in astrophysics. The Advanced X-Ray Astrophysics Facility will provide a scientific opportunity that is unlikely to be repeated for many generations. The closest supernova to occur near Earth since the invention of the telescope was seen last year, and it can be studied by the facility, provided that launch occurs by 1995, before the X rays fade.

The sequence of major and moderate missions for the years 1990 through 1994 is detailed below. The major missions, in order of priority, are:

- Joint initiation of Comet Rendezvous Asteroid Flyby and Cassini [Saturn] missions. We place this initiative as the highest priority for major missions because development must be started now to assure a robust solar system exploration program at the end of this century.
- The Earth Observing System will place a suite of instruments in low-Earth orbit to make comprehensive observations of Earth's atmosphere, oceans, land surfaces, and biota.
- The Space Infrared Telescope Facility, the fourth Great Observatory, will study the very cold regions of space: locations where the cosmic gas and dust condense into stars, cool objects in the solar system, and infrared-emitting extragalactic objects.
- The Solar Probe will be humanity's first direct exploratory venture to the vicinity of the Sun. It will study the unexplored region between 4 and 60 radii from the Sun, where the solar wind begins to flow at supersonic speeds.

In the event that resources do not permit the implementation of a major mission, the moderate missions described below will be pursued in order of priority:

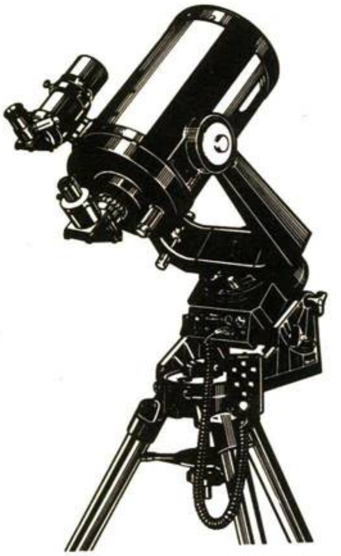
- The High-Resolution Solar Observatory is a scientific platform for performing investigations of the Sun's fine-scale magnetic structures.
- The Lunar Observer will conduct a one-year polar mapping mission to measure the Moon's global surface mineral and elemental composition and to assess global resources.
- Gravity Probe-B is designed to be a cornerstone test of general relativity. It will measure both the distortion of the "fabric of space time," imposed by the Earth's presence, and the subtle dragging of this fabric, predicted to result from the Earth's rotation.

Our vision sees NASA and the United States enjoying an exciting and productive era in space science, with leadership in space manifested by visible achievements that are second to none. ☐

Excerpted from Strategic Plan 1988: A Strategy for Leadership in Space through Excellence in Space Science and Applications, *NASA's Office of Space Science and Applications, May 1988. OSSA directs NASA programs in astrophysics, solar system exploration, space physics, and Earth science.*

Mars and Meade... Magnificent!

FREE FREIGHT



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(Certain restrictions apply, call or write for details.)

Meade 2080 LX5 $1569

The ultimate 8" Schmidt-Cassegrain telescope, ideal for viewing Mars, Jupiter, and the Universe. Features:

- AC/DC quartz drive with control
- 2x correction speed, 8x scanning speed in all directions
- adjustable field tripod and wedge
- much more

Meade 2120 LX-5 $1965

The Ultimate 10" Schmidt-Cassegrain.

Accessories for Meade LX5

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T-mount (specify camera model)	$12
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tube balance system 2080/2120	$99
2" guidescope for 2120	$129
2047/2048 mount	$199
1.25" eyepiece holder	$24
tele-extender	$35
wide field adapter system	$119
911 nebula filter	$109
8" dew shade	$59
10" dew shade	$99
tripod carrying bag	$89
1200A electric focus motor	$149

Meade 6600 CD $499

Fast 6" f/5 German equatorial reflecting telescope. Excellent for wide field viewing, or add the optional quartz clock drive with corrector for easy astrophotography. Includes optical tube, 25mm eyepiece, 6x30 finder, equatorial mount and adjustable tripod. A super buy on these fine scopes with slight cosmetic defects. Includes full Meade lifetime warranty covering both mechanical and optical systems.

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A complete 1000mm f/10 Schmidt-Cassegrain telephoto lens package for great photography. With a free star diagonal, eyepiece holder, and 25mm eyepiece for sharp viewing.

Meade 2080 LX3 $1349

Last chance to purchase this revolutionary 8" Schmidt-Cassegrain telescope!

Meade DS-10A $829

Complete 10" deep space reflector with 2" focuser and clock drive.

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polar alignment finder 6600	$39
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nebula filter 1.25"	$79
6 filter set 1.25"	$69

Meade MTS-SC8 System $915

Capture Mars with this high-powered 8" Schmidt-Cassegrain. Sturdy observatory pier mount with LX3 drive offers accurate tracking control for sharp photographs. Includes: 25mm eyepiece, 1.25" eyepiece holder, prism diagonal, 8x50 finder, LX3 drive system, AC and DC power cords, and pier mount. Quality high-power astro photography has never been possible at a lower price!

Meade MTS-SC8 System with MCOG $995

Meade MTS-SN6 System $569

Fast 6" f/5 Schmidt-Newtonian telescope is great for wide-field exploration. Sharp, coma-free viewing and photography. Complete with AC clock drive, setting circles, observatory pier mount, and eyepiece.

Meade MTS-SN6 System with MCOG $599

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Spectacular Savings on the finest eyepieces available!

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Super Plossl 56mm	$151
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Super wide angle 18mm	$124
Super wide angle 24.5mm	$129
Super wide angle 32mm	$184
Super wide angle 40mm	$231
Ultra wide angle 4.7mm	$124
Ultra wide angle 6.7mm	$154
Ultra wide angle 8.8mm	$184
Ultra wide angle 14mm	$197

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Thousand Oaks 8" solar filter	$129
Tuthill 10" No-Du	$129
Tuthill 8" No-Du	$89

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SOLAR ACTIVITY AND EARTH'S CLIMATE

The energy emitted by the Sun relates directly to the level of solar activity, according to a new study. This means that when sunspots are numerous — the most obvious indicator of solar activity — the Sun radiates more energy than when sunspot numbers are low. The variations in energy output could have a significant effect on Earth's climate.

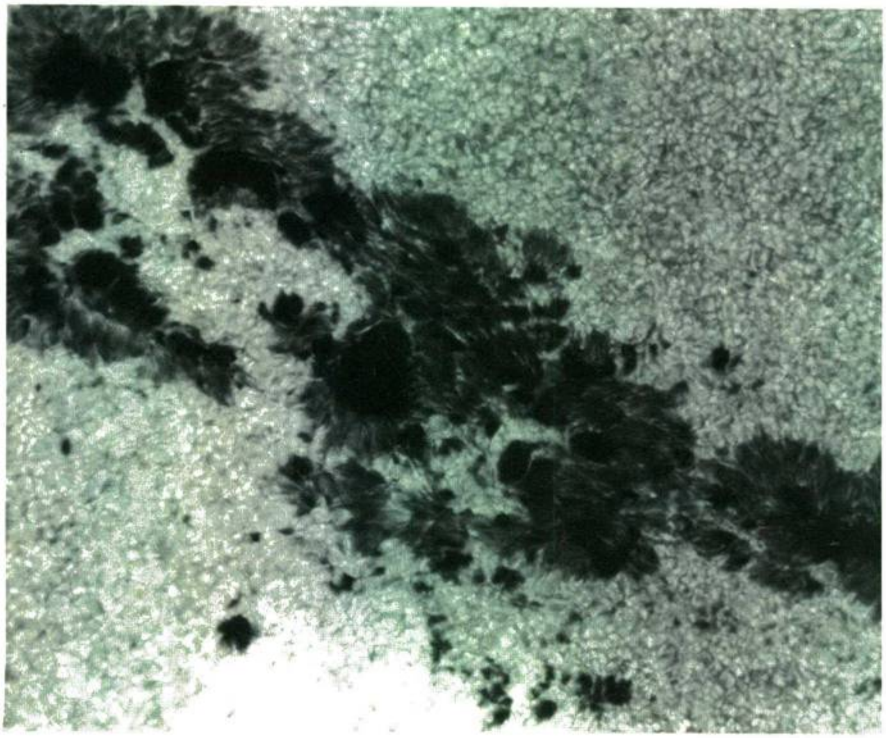
Richard Willson of the Jet Propulsion Laboratory and Hugh Hudson of the University of California at San Diego discovered the correlation between the Sun's output and solar activity from data returned by the *Solar Maximum Mission* (*SMM*) satellite. They reported their findings in the journal *Nature* (April 28, 1988).

Willson and Hudson base their findings on data taken by the ACRIM experiment (short for Active Cavity Radiometer Irradiance Monitor) on *SMM* between 1980 and late 1987. Between late 1980 (just after the peak in the last solar cycle) and mid-1985, solar activity declined. During the same period ACRIM measured a steady decrease in the luminosity of the Sun. The Sun's output declined by 0.019 percent per year for a total drop of about 0.1 percent over the five years.

Between mid-1985 and mid-1987, when the Sun's activity level was low, solar output was also steady but low. In late 1987, as solar activity began to rise again, the ACRIM experiment measured an increase in solar output.

Scientists have yet to pinpoint the cause of the effect, which runs counter to common sense. (Sunspots are, after all, darker than nonspotted regions.) Some astronomers believe the lower output of sunspots is more than compensated for by the increased emission of faculae — abnormally bright patches usually associated with sunspots.

The trend of the observations is clear, although the implications for Earth are more difficult to assess. A slight increase or decrease in the amount of solar energy reaching Earth is enough to produce substantial variation in Earth's past — from ice ages to global tropical conditions. The new research may offer a way to tie these variations to an easily observable aspect of the Sun.



SUNSPOTS AUGUR A BRIGHTER SUN, according to researchers who have linked the Sun's luminosity to solar activity. If the relationship is confirmed, solar activity may prove useful in studying the Sun's effect on Earth's climate.

Unfortunately a cyclic change in the Sun's luminosity of the magnitude detected would not cause a measurable climatic change. Only if the Sun remained bright or dim for a longer period would the effect rise above natural changes here on Earth.

One such period may have occurred three centuries ago. Between about 1640 and 1710 the number of sunspots, as well as other indicators of solar activity, was very low. Known as the "Maunder Minimum," this period coincided with the most severe drop in world temperature during the past one thousand years. A similar period of low solar activity and low temperatures, called the Sporer Minimum, occurred between 1400 and 1510.

Willson and Hudson point out that the change in temperature during these periods agrees with their preliminary findings: a less active Sun emits less energy, which in turn causes Earth to turn colder.

Astronomers naturally want to see the observed relation between solar energy output and solar activity continue, at least through the upcoming maximum in the early 1990s. If the pattern continues, astronomers will have an important new tool for studying the effects of the Sun on Earth's climate.

BEATING LIGHT POLLUTION WITH 'GOOD LIGHT'

Instead of taking an "antilight" tactic in the battle against light pollution, the newly formed International Dark-Sky Association intends to promote the use of "good light" — fully shielded, low-pressure sodium lights. The group, organized in January by astronomer David Crawford of Kitt Peak National Observatory and amateur astronomer Tim Hunter, will be a clearinghouse of information that emphasizes solutions to the light-pollution problems of professional and amateur astronomers.

"Light pollution wastes energy and money and contributes to air and water pollution," says Hunter, president of the group. "But if you could convince manufacturers to make only proper, shielded lights, a lot of the problem would be solved in a generation."

The organization is currently preparing "one-sheeters" on a variety of aspects of good lighting: what types of lighting are available, who manufactures them, the economics of light pollution, and examples of light pollution ordinances passed around the country.

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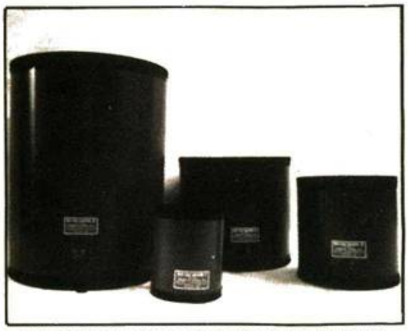

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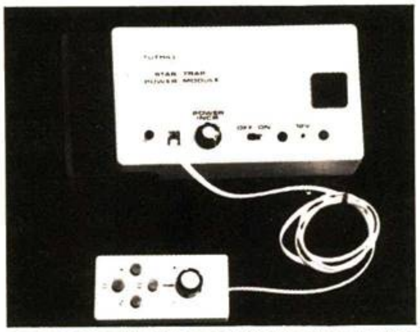

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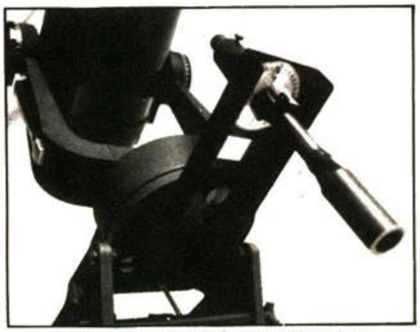

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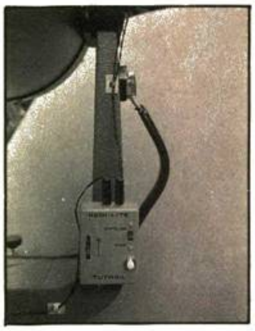

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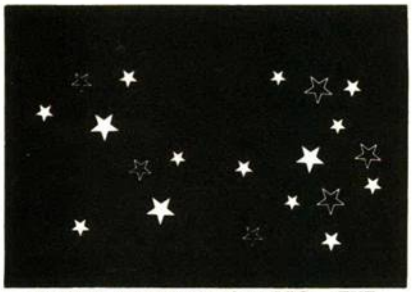

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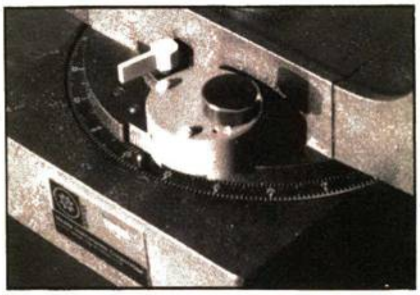

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If you're interested in becoming a member of the International Dark-Sky Association, write to the organization at 3545 North Stewart, Tucson, AZ 85716.

LICK REFURBISHES 36-INCH LENS AND DOME

Lick Observatory is refurbishing its historic 36-inch telescope and the dome that houses the telescope. Earthquake damage had made the dome unsafe, and moisture had harmed the front element of the hundred-year-old lens.

"Over the last several years," said Joe Calmes, assistant director of the observatory, "we've requested funds from the California legislature for the restoration of the building. It has provided them and the restoration is under way."

Damage to the outer brick wall of the dome was first noticed about fifteen years ago. A strong earthquake in April 1984 made the west wall bulge, and the dome was closed in April 1985. To repair the wall, a contractor will remove sections of the damaged outer wall and spray concrete against the undamaged inside wall.

Also refurbished is the front surface of the 36-inch telescope lens. Decades of daytime heat and moisture had produced a network of fine cracks in the surface called "crazing." "Apparently it crazed as a result of Alvan Clark's not really polishing out all the microfractures from the initial grinding," said Calmes. "Condensation on the glass aided and abetted the problem."

The lens went into service early in January 1888 and for many decades was the workhorse of Lick Observatory. In 1981 Lick opticians removed the historic lens from the telescope, ground off about 1 millimeter of glass, and repolished the lens. "But we noticed that we couldn't use it at full aperture; we had to stop it down to 22 inches," said Calmes.

After careful assessment of the lens, optician Dave Hilyard of the Lick optical shop refigured the front element to an aspheric surface, at times even using his thumb to polish narrow zones only half an inch wide, just as Alvan Clark had a century earlier. Optical tests indicate that the lens is now as good as or better than it was originally.

The 36-inch refractor is used mostly for precise measurement of stellar positions, taking "second epoch" photographs for comparison with images taken long ago, and double star work.

"Our hope," said Calmes, "is that the restoration will be completed by December of this year so we can have a rededication of the facility on the 101st anniversary of first light through the 36-inch refractor on January 7, 1989."

THE RESTORED 36-INCH LENS will be back in service by January 1989. Optician Dave Hilyard refigured the front element of the lens.

Space News

REACHING FOR THE MOON

Can the absolute distance to other galaxies or even to the center of our own be measured by finding extremely distant "standard candles"? Can the velocity of matter close to the centers of quasars be measured to prove whether or not supermassive black holes lurk within these objects?

Not from Earth, and maybe not even from Earth orbit. But astronomical measurements like these could be made from an observatory on the far side of the Moon, according to Jack O. Burns of the University of New Mexico's Institute of Astrophysics. Burns was among the more than five hundred scientists and engineers at the second Lunar Bases and Space Activities of the 21st Century symposium held April 5-7 in Houston.

Former NASA deputy administrator Hans Mark stated at the meeting that a lunar observatory should be NASA's single goal after the Space Station. Mark envisions an international facility, operated with the Soviet Union and other countries, which could begin an era of international cooperation sooner and with less risk than a Mars mission.

But will we ever get back to the Moon? Dale Myers, NASA deputy administrator, said, "This year's NASA budget is the key budget for many years. If there is any cut in the president's budget, we lose an important part of NASA."

Myers' unmistakable excitement about NASA's newfound ambition for human deep-space exploration typified the mood of the meeting. This enthusiasm, together with the view that this year's combination of public, congressional, and presidential support might represent the last chance to get back into the solar system race before other nations establish an unbeatable lead, was set against a profound realization that federal budget deficits may well make it all impossible.

The Space Station was viewed as essential to future plans by most speakers at the meeting. "Without the Space Station we don't do a lunar base," said Myers. "Yet the Space Station is very difficult to sell to Congress because it has so many facets." The Space Station would teach us how to live and work in space, develop closed-loop life-support technology, and test in space the systems and subsystems needed for lunar and Mars bases.

Wendell Mendell, organizer of the conference and long-time lunar base advocate at Johnson Space Center, noted that public support may not automatically translate into federal support for a lunar base. "Who is going to pay us to go exploring? The American people may support us, but we aren't talking to the American people, we're talking to the representatives of the American people, who have a lot of other things on their minds."

But, as far as lunar base planning inside NASA goes, Mendell is optimistic about the future. "For the first time in a long time NASA is working on a long-range plan: that's the ray of hope." — *Donald F. Robertson*

CREW ESCAPE SYSTEM READY FOR SHUTTLE

Beginning with the flight of *Discovery* this fall, space shuttle astronauts will have a way to evacuate the orbiter in an emergency. Although the escape system can only be used under certain circumstances

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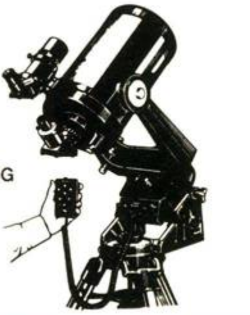

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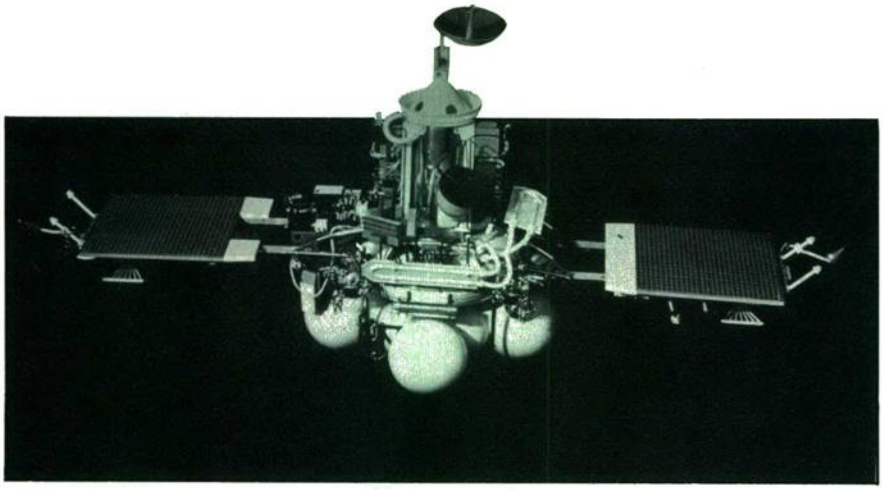


AFTER REACHING MARS, the Soviet *Phobos* spacecraft will drop plaques on the Martian moons commemorating Asaph Hall, the U.S. discoverer of the moons.

— when the orbiter is at a low altitude and in level, controlled flight — it does allow the astronauts to parachute safely out of the shuttle during launch and landing.

The problem with getting out of the shuttle is that the crew cabin is ahead of the wings. An astronaut bailing directly out of the crew hatch on the left side of the orbiter would be thrown into the wing.

NASA's solution is a ten-foot-long, three-inch-diameter aluminum pole that would extend from the mid-deck area out through the hatch. Astronauts would scramble down from the flight deck to the lower mid-deck where the pole, attached to the ceiling, would be extended out through the hatch. Each astronaut would attach a cord from his or her parachute harness to a ring on the pole, roll through the open hatch, slide down the pole, and drop off the end of the pole below the wing. The entire shuttle crew could escape in a minute and a half.

The escape system, designed at NASA's Johnson Space Center, can only be used when the shuttle is below 20,000 feet and is in a controlled, relatively level glide.

SOVIET MISSION CARRIES U.S. COMMEMORATIVE PLAQUE

The moons of Mars were discovered 111 years ago this month by U.S. Naval Observatory astronomer Asaph Hall. Two small reproductions of Hall's discovery notes are now on their way to the Martian moons aboard the Soviet *Phobos* spacecraft.

The aluminum plaques, photographic transfers of Hall's logbook from the night he discovered Phobos (August 17, 1877), are attached to the lander probe that will be dropped onto Phobos and possibly Deimos next spring.

The idea of sending the commemorative plaques to Mars was suggested by Hall's great-great-grandson, Andrew Hyde, to NASA's solar system exploration division. The Soviet Academy of Science approved the idea and the plaques were formally presented to Soviet scientists in April.

"My great-great-grandfather has always been a source of inspiration to me and my family," said Hyde. "Never, in his wildest imagination, could he ever have imagined this." Hall found the two moons in a search for Martian satellites with the Naval Observatory's 26-inch reflector, then the world's largest telescope.

U.S. and Canadian readers interested in seeing a somewhat smaller-scale version of the *Phobos* spacecraft can visit the Royal Ontario Museum in Toronto this summer. A two-foot by three-foot *Phobos* model, the first to arrive in North America from the Soviet Union, is on exhibit in conjunction with the museum's summer planetarium show, "Mars: The Journey Begins," which runs through September 5.

NEW SPACE EXPLORATION MAGAZINE LAUNCHED

Final Frontier, a bimonthly magazine devoted to space exploration, appeared on newsstands across the country this spring. The premiere April issue featured articles on the return of the space shuttle, the future of *Voyager 2*, Soviet space artists, and the otherworldly experience of life in Antarctica. Lunar architecture, the search for extraterrestrial intelligence, and Japan's role in the space station were featured in the June issue.

For subscription information, write to *Final Frontier*, 339 Union Plaza, 333 North Washington Avenue, Minneapolis, MN 55401.

Amateur News

RECORD YEAR FOR TEXAS STAR PARTY

Seven dark nights between May 8 and 15, 1988, gave amateur astronomers at the tenth annual Texas Star Party the chance to observe planets and deep-sky objects the way most observers never see them at home. This year's attendance of 625 set a new record for the event, which is held at the Prude Ranch in Fort Davis, Texas. The TSP has become synonymous with dark skies and the free exchange of ideas among backyard astronomers.

Those interested in the solar system had plenty to see. Participants used everything from binoculars to 24-inch Dobsonian telescopes to observe Venus, Saturn, Uranus, and Neptune in the evening sky. As soon as dazzlingly bright Venus set, the zodiacal light was plainly visible as a diffuse band crossing most of the sky. Comet Liller, placed near the north celestial pole and visible all night, glowed at 5th magnitude and sported a 3°-long tail. Those who stayed up until early morning aimed telescopes at Mars.

The darkness of the Texas sky lends itself to deep-sky observing. Each night soon after twilight dozens of telescopes pointed toward the bright globular cluster Omega Centauri. "It's become sort of a symbol of the TSP," said Dave Clark, the TSP's organizer. Observers also viewed many Messier objects and photographed starfields scattered across the sky. "The Milky Way was so bright I really thought it was a band of clouds," said Bobby Valentine of Florence, Alabama. "I thought we were clouded out and then realized we were in for a fantastic night of viewing!"

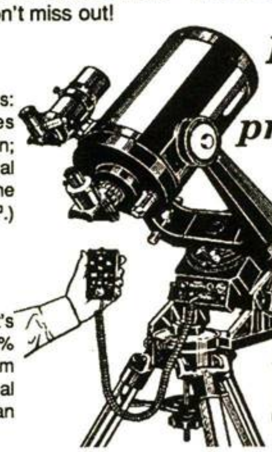
Deep-sky observers concentrated on hunting down faint globular clusters, quasars, clusters of galaxies, and obscure planetary nebulae. The availability of large scopes at this year's TSP — *"Hey, can we look for the Corona Borealis cluster in your 24-incher?"* "Sure!" — made group observing projects spring up all over the telescope fields.

Holding the line on prices!

Meade and Celestron told us a while back that they would be raising their prices in June. At the time this ad was written (mid-May), we didn't know what the new prices would be, so we decided to lay in an extra supply of best-selling telescopes. That way, we could continue to offer you low, low prices – even after the official price increases went into effect. We carry only name-brand telescopes and accessories – from Meade, Celestron, Edmund, TeleVue, Questar, Bausch & Lomb, Lumicon, Motofocus, University Optics, Vernonscope, DayStar, Zeiss, and others – *and we save you money on all of them!* These prices are good through August 31 only, and some quantities are limited, so don't miss out!

A $3600 Meade 2080/LX5 for $1595!

Here's a superb *56% savings* on a superb 8" telescope – the state-of-the-art Meade 2080/LX5. You get all these features: the latest multi-coated optics group; 9 x 60mm illuminated polar axis finder; 2" mirror star diagonal with 1.25" adapter; 1.25" Series 4000 Super Plossl eyepiece; quartz-controlled electronic drive with power adapters for AC, DC, and penlight battery operation; hand control with built-in map light and controls for optional electric focuser, drive corrector, and 8x image scanning; equatorial wedge; adjustable height tripod; foam-lined carrying case with lock; lifetime warranty, and more! *$3600 list,* **for only $1595!** (The optional $\$160^{00}$ #39 dec motor that converts the LX5 drive into a dual axis drive corrector for astrophotography is only $\$99^{50}$.) Less than 70 available at this special sale price, so don't wait. Prices go up when these are gone.



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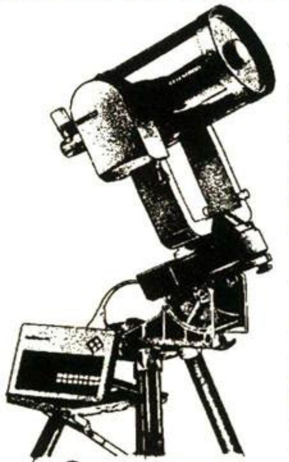

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A $6800 Celestron Compustar 8 for $3845!

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A $3122 Celestron Powerstar *III* for $1599!

Take a justly famous and optically magnificent Celestron Powerstar II – add some extra features, like a T-adapter, tele-extender, dew shield, and Sky Maps – and you have the new Powerstar *III*. You get all these other features, too: the latest Starbright optical coatings; 8 x 50mm illuminated polar axis finder; 26mm Plossl (77x) and 7mm ortho (286x) eyepieces; quartz-controlled electronic drive with power adapters for AC and penlight battery operation; drive corrector/hand control with built-in map light and controls for optional electric focuser; equatorial wedge; adjustable height tripod; heavy duty Samsonite-type foam-lined carrying case; lifetime warranty, and more! *$3122 list,* **for only $1599!** (An optional $\$160^{00}$ declination motor that converts the drive into a dual axis drive corrector for astrophotography is only $\$112^{50}$.) Quantities are *very* limited on this special production run telescope, so don't miss out.

A $995 TeleVue Oracle 3 for $649!

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The latest Celestron C90 spotting scopes, from $379!

Celestron has updated their best-selling C90 spotting scopes – and we've got them all in stock! These are not the discontinued, inverted finder image, uncoated models that some dealers offer. These are the very latest models – some with *multi-coated* optics for visibly higher light transmission and increased contrast, some with rubber armor for hard use in the field. Each has an 8x finder with a very wide 7° field and upright/correctly-oriented images, plus a 45° prism diagonal that provides both upright and correctly oriented images *and* a comfortable viewing angle. Each comes with a 33x eyepiece and a unique Samsonite-type carrying case fitted to hold your camera and photo accessories, as well as the spotting scope! They're super 3.5" f/11 spotting Maksutov scopes at sensible prices that save you over 40%!

C90, erect image finder, 45° erect image diagonal, 33x eyepiece, case, *$650 list*	$\$379^{00}$
C90, as above, but with multi-coated optics, *$710 list*	$\$409^{00}$
C90, same as basic C90 above, but with rubber armor, *$730 list*	$\$419^{00}$
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Featured evening talks included a discussion of deep-sky observing techniques by Lowell Observatory astronomer Brian Skiff, the story of the evolution of Dobsonian telescopes by telescope-maker John Dobson, and a tour through seven areas of galaxy research by Jay Gallagher, director of Lowell.

Amateur talks included an astrophotography workshop by Klaus Brasch, Robert Reeves, and Mike Mayerchak; a slide show from the March 18 solar eclipse by Joel K. Harris; and a discussion of binocular telescopes by Robert Suding.

During a council meeting of the Southwest Region of the Astronomical League, a national group of astronomical societies, chairman Dave Clark announced a victory in the fight against light pollution in Texas. The organizers of the TSP and the league's Southwest Region are donating $6,000 in profits from the TSP to help convert the county surrounding the star party to shielded, low-pressure sodium lighting. The bulk of this money will go to replacing existing mercury-vapor lights in Fort Davis and across Jefferson Davis county and installing sodium lights. This will keep light pollution in the county to a minimum, and it is the first time such a deal has been struck between a government and an astronomical society.

From its humble beginnings the Texas Star Party has grown to become one of the three main gatherings of amateur astronomers in the United States. Why do people come to the TSP? "There's no other event where I can learn so much in such a brief time," said Biff Bigbie of Ardmore, Oklahoma. Fellow Oklahoman Robin Roads came to "observe, try out my new camera, and have fun." Bryan Shumaker of Detroit came because "it's great to meet people who enjoy doing what I do." Joel Harris of Burbank, California, came because "it's the most observationally serious conference in amateur astronomy . . . the meeting is organized so you can make the most of the extremely dark sky." Jim Rose of Midland, Texas, came to "renew old acquaintances under the darkest skies in the States."

THE SUMMER MILKY WAY dominated the observing time of over six hundred amateur astronomers at this year's Texas Star Party.

KODAK SPONSORS AUSTRALIAN ASTROPHOTO CONTEST

Astrophotographers who have shot the night sky from Australia or New Zealand can enter a special photo contest being held in conjunction with this year's Australian bicentennial.

Astrophotos for "SkyWatch 88," sponsored by Kodak, the township of Coonabarabran, New South Wales, and Siding Spring Observatory, will be judged in two categories: those taken through a conventional camera and those taken through an amateur telescope. David Malin of the Anglo-Australian Observatory will select the top three photos in each category, and the winners will share the $1,000 in prize money.

To get contest rules or submit photos, write to the Coonabarabran Bicentennial Committee, c/o Coonabarabran Shire Chambers, John Street, NSW 2357, Australia. There is no entry fee for the contest. Enclose a stamped, self-addressed envelope if you want your photos returned. Deadline for entries is December 31, 1988.

SEE THE SKY THROUGH A 107-INCH TELESCOPE

McDonald Observatory near Fort Davis in west Texas is once again offering public viewing through its 107-inch telescope, the fifteenth largest telescope in the world. Viewing through the telescope is part of McDonald's program for visitors.

The viewing program is offered one night each month and runs one-and-a-half hours. The program includes a presentation by astronomers, a question-and-answer session, and observing the Moon or the planets visible on the viewing night. In addition, the observatory's visitors' center is open daily except for holidays and includes exhibits, solar viewing, and guided tours.

The public viewing nights were suspended in August 1986 to allow for the restructuring of the visitors' program and resumed March 30, 1988.

Reservations are required two months in advance to take part in the viewing program, which is limited to sixty people a session. Write to the W. L. Moody, Jr., Visitors' Information Center, Box 1337, Fort Davis, TX 79734, for reservations and information. A small donation is requested.

ASTRONOMY RETAIL SHOW DRAWS CROWD

Over one thousand enthusiastic amateur astronomers attended the New England Astro-Fest I, the first East Coast retail astronomy hobby show, held April 23 in Windsor Locks, Connecticut.

According to show sponsor Bob Rinaldi of New England Astro-Optics, "I did what the camera industry does. I held a photo exhibition with seminars going on the side. Totally commercial." The fifteen vendors reported excellent sales, Rinaldi said.

Astro-Fest gave customers the opportunity to ask equipment manufacturers questions, to see and examine new products, and to purchase products that included telescopes, binoculars, eyepieces, accessories, books, star atlases — even meteorites!

"Astro-Fest fills a void that's been untouched on the East Coast. It fills the void that Stellafane doesn't fill," Rinaldi claimed, "[The customers] were hungry for it." Stellafane bans commercial exhibitors.

Next year Rinaldi plans to have swap tables as well as commercial exhibitors. "There was a big demand for them, so we'll add them. We're already working on Astro-Fest II for next May." ☐

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COSMIC ORIGINS OF THE ELEMENTS

The evolution and death of stars provide the fuel to create heavier elements from the hydrogen created in the Big Bang.

by Gary Bennett

Somewhere between the Big Bang and the formation of the Sun came the carbon in this paper and the iron in this ink.

The story of nucleosynthesis — the origin of the elements — ties the vastly great to the submicroscopically small and links the earliest moments of the universe to today. It unites astronomy with physics, chemistry, and even geology in a colorful tapestry that weaves together you, the stars, and the Big Bang itself.

The elements were created during two epochs of the universe. The first epoch closed out the Big Bang and divides the end of that explosion from the beginning of the universe we know. The second epoch began when the first stars were born and continues down to today.

The Dawn of Matter

About 15 billion years ago an infinitesimally small, infinitely dense and hot point of energy erupted in a titanic explosion that created all of space and time and matter and energy — we call it the Big Bang.

Packets of energy called photons raced through the early universe. Photons are massless, neutral particles that travel at the speed of light and carry electromagnetic energy, such as sunlight. In a sense the universe at this stage *was* light.

The photons' energy depended on the temperature of the universe. Although the temperature had cooled a lot since the inception of the universe less than a millionth of a second before, it was still enormously hot — hundreds of times hotter than a detonating hydrogen bomb. At these temperatures, matter emerged as elementary particles when photon collided with photon. Einstein's famous equation $E = mc^2$ beautifully documents this early era when energy and matter flowed back and forth interchangeably. This was also when other massless packets of energy such as neutrinos sprang into existence. But unlike photons, neutrinos very rarely interact with matter.

The photon collisions produced particles such as electrons, protons, and neutrons. They also produced antiparticles — bits of matter with the same mass but the opposite electrical charge. (The antiparticle of the negatively charged electron, for example, is the positively charged positron.) When photon smashed into photon, it created particle and antiparticle pairs shooting off in different directions. Once separated, the particles lasted but instants before each collided with its antiparticle, whereupon the particles annihilated one another and set two photons flying free again.

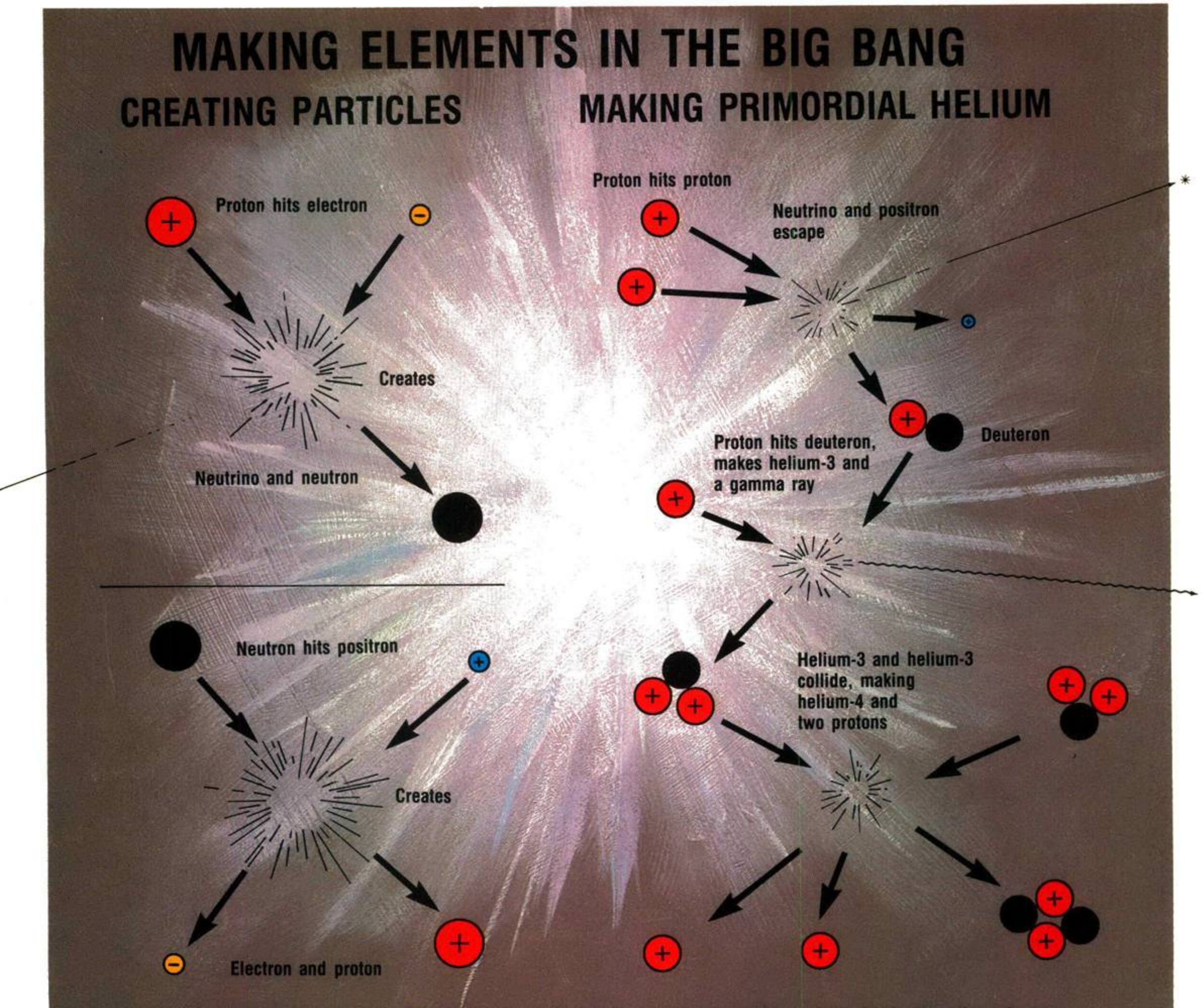
All the while the universe was expanding, cooling, and losing energy. The four presently known physical forces appeared — gravity, electromagnetic, and the weak and strong nuclear forces. At one critical moment the universe cooled enough to switch off the free interchange between photons and particles. In one final, annihilating burst the universe turned almost all its protons, neutrons, and electrons into light. This was truly momentous, for today's universe of matter very nearly disappeared forever in that instant. Only a slight overabundance of particles relative to antiparticles allowed particles to win out — and our present universe to exist.

These leftover neutrons, protons, and electrons continued to transform as they collided with one another. Negatively charged electrons smashed into positively charged protons to produce neutrons (no electric charge) and neutrinos (no electric charge). Reactions also proceded in reverse: a neutrino might react with a neutron to produce an electron and a proton. Likewise, positrons collided with neutrons to produce protons and antineutrinos and vice versa.

Laboratory experiments with big atom-smashers show that out of these collisions came the primordial elements. Hydrogen, the simplest and lightest element, formed when a single proton captured an electron. Like a tiny Sun ruling over a Lilliputian solar system, the proton has a mass 1,836 times that of the electron — only electromagnetic force, not gravity, holds the system together.

The strong nuclear force is responsible for creating another building block, the deuteron, which consists of a proton and a neutron. If two deuterons collide with the right energy, they bond and form a nucleus of helium, the second simplest and lightest element. The neutrally charged neutron acts as the necessary "glue" that lets the two identically charged protons bind together.

Hydrogen and helium seem easy to produce, but what about other elements? Making more complex elements was quite difficult under the conditions prevailing at the end of the Big Bang. Several nuclear bottlenecks blocked the way.


MAKING ELEMENTS IN THE BIG BANG
CREATING PARTICLES
MAKING PRIMORDIAL HELIUM
Proton hits electron
Creates
Neutrino and neutron
Neutron hits positron
Creates
Electron and proton
Proton hits proton
Neutrino and positron escape
Deuteron
Proton hits deuteron, makes helium-3 and a gamma ray
Helium-3 and helium-3 collide, making helium-4 and two protons

In the first split seconds of the universe, particles transformed freely in high-energy collisions (left). By the time the universe was a minute old, it had cooled enough to fuse hydrogen into helium (right).

The first bottleneck was the deuteron itself. The bond between the neutron and the proton that make up the deuteron nucleus is not very strong. Until the temperature of the universe dropped below a billion kelvins, the universe's energy was sufficiently high to tear any deuteron apart before it could capture another proton and neutron and become helium.

Once the universe cooled enough for deuterons to survive, the remaining free neutrons either broke down by radioactive decay into a proton, an electron, and an antineutrino or were captured by deuterons to form the nuclei of tritium. But tritium is an unstable substance and soon decays to helium-3, made of two protons and one neutron. Helium-3 could also occur when a single proton collided with a deuteron. Though stable, helium-3 readily captures any stray neutron and becomes helium-4, the second most prevalent element in the universe.

(The numbers following each element give the total number of protons and neutrons in the atom's nucleus; physicists call them "mass numbers." Elements with the same number of protons but a different number of neutrons are called *isotopes*. For example, helium-3 and helium-4 are both isotopes of helium, and helium-4 carries one more neutron than helium-3.)

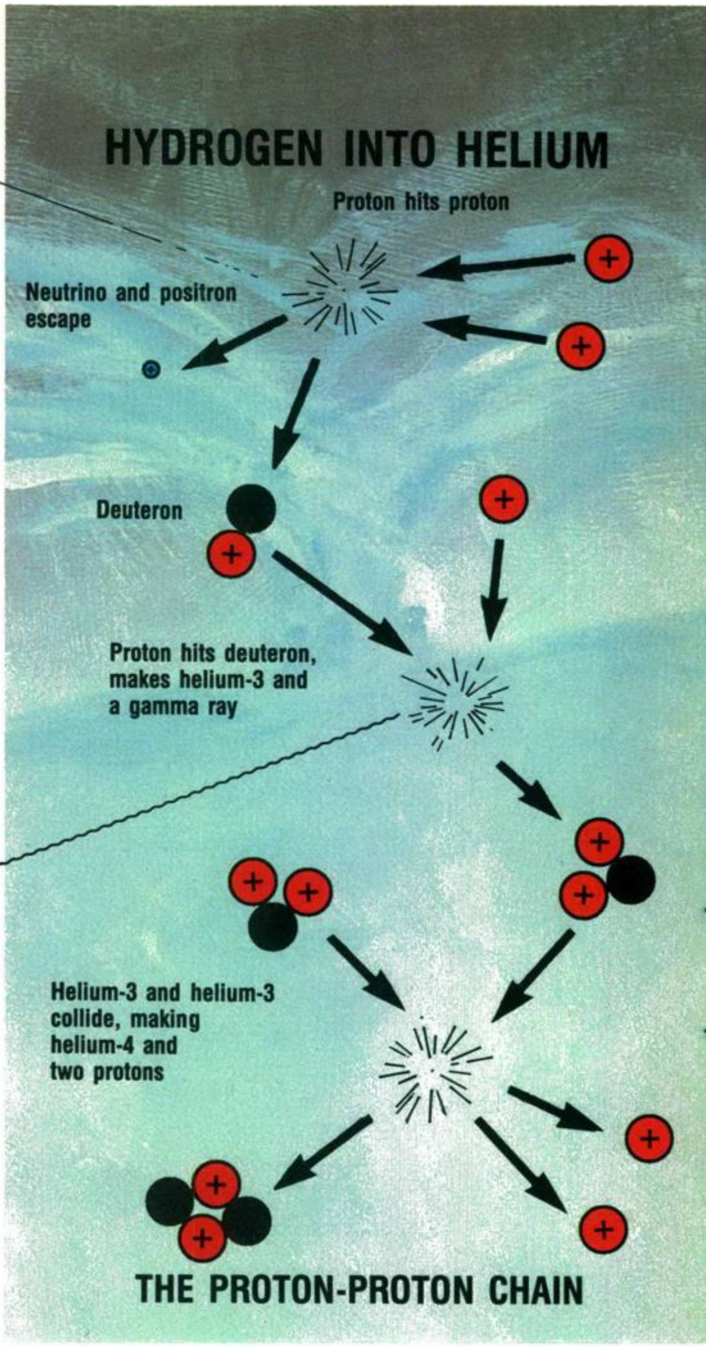
The second bottleneck to the formation of elements heavier than helium was that nature does not like certain combinations of particles. For example, there are no stable nuclei with a mass number of 5. If a helium-4 nucleus absorbs a neutron to become helium-5, it decays immediately. Similarly, if helium-4 absorbs a proton to form lithium-5, it too decays immediately. Mass number 8 is also unstable, so if two helium-4 nuclei tried to bond, they would promptly break apart. These two unstable mass numbers stood like a wall in the way of making more complex elements.

You might think that with all the atoms whizzing around, three or more might collide and sneak past the magic 5 or 8 mass-number barrier. But it was already too late — the universe had cooled too much. By this point the densities of energy and particles pervading the cosmos were too low for multiple collisions to happen with any high probability.

One exception may have occurred just before the era of Big Bang nucleosynthesis ended. A limited amount of lithium, the next element heavier than helium, could have formed from either of two interactions. If helium-4 and tritium collided, lithium-7 would result. Also, helium-4 and helium-3 could collide to make the relatively unstable nucleus of beryllium-7. The beryllium-7 nucleus would exist long enough to absorb one electron and change into lithium-7, the most abundant lithium isotope on Earth.

At this point — roughly four minutes after the Big Bang — the first epoch of nucleosynthesis was over. And what a cheerless place the universe was! With a temperature of a billion degrees but steadily cooling and expanding, the universe had reached a nuclear dead end. Unless some other process intervened, the universe was doomed to consist only of about 76 percent hydrogen, 24 percent helium, and probable trace amounts of lithium.

Earth, and life as we know it, did not — and could not — exist.


HYDROGEN INTO HELIUM
Proton hits proton
Neutrino and positron escape
Deuteron
Proton hits deuteron, makes helium-3 and a gamma ray
Helium-3 and helium-3 collide, making helium-4 and two protons
THE PROTON-PROTON CHAIN

Stars: Round One

As hydrogen and helium spewed forth from the primeval fireball, instabilities in the material formed and grew. Vast clouds of hydrogen and helium, each billions of times more massive than the Sun, fell together under the pull of gravity to make protogalaxies.

Inside the newborn galaxies, turbulent regions of gas coalesced under gravity into stars. Astronomers call these earliest stars Population III and think that most of them contained enough material to make anywhere from one hundred to three hundred Suns each. With lifetimes only a few million years long, these behemoths became the nuclear pressure cookers that took the universe beyond hydrogen and helium.

As gravity pulled gas toward the center of each protostar, it released energy that increased the temperature of gas particles in the central core. As the temperature there reached at least 100 million kelvins, the hydrogen nuclei (protons) were moving quickly enough to race past the barrier of their mutual electrical repulsion and to begin interacting with one another in a chain reaction called the proton-proton chain.

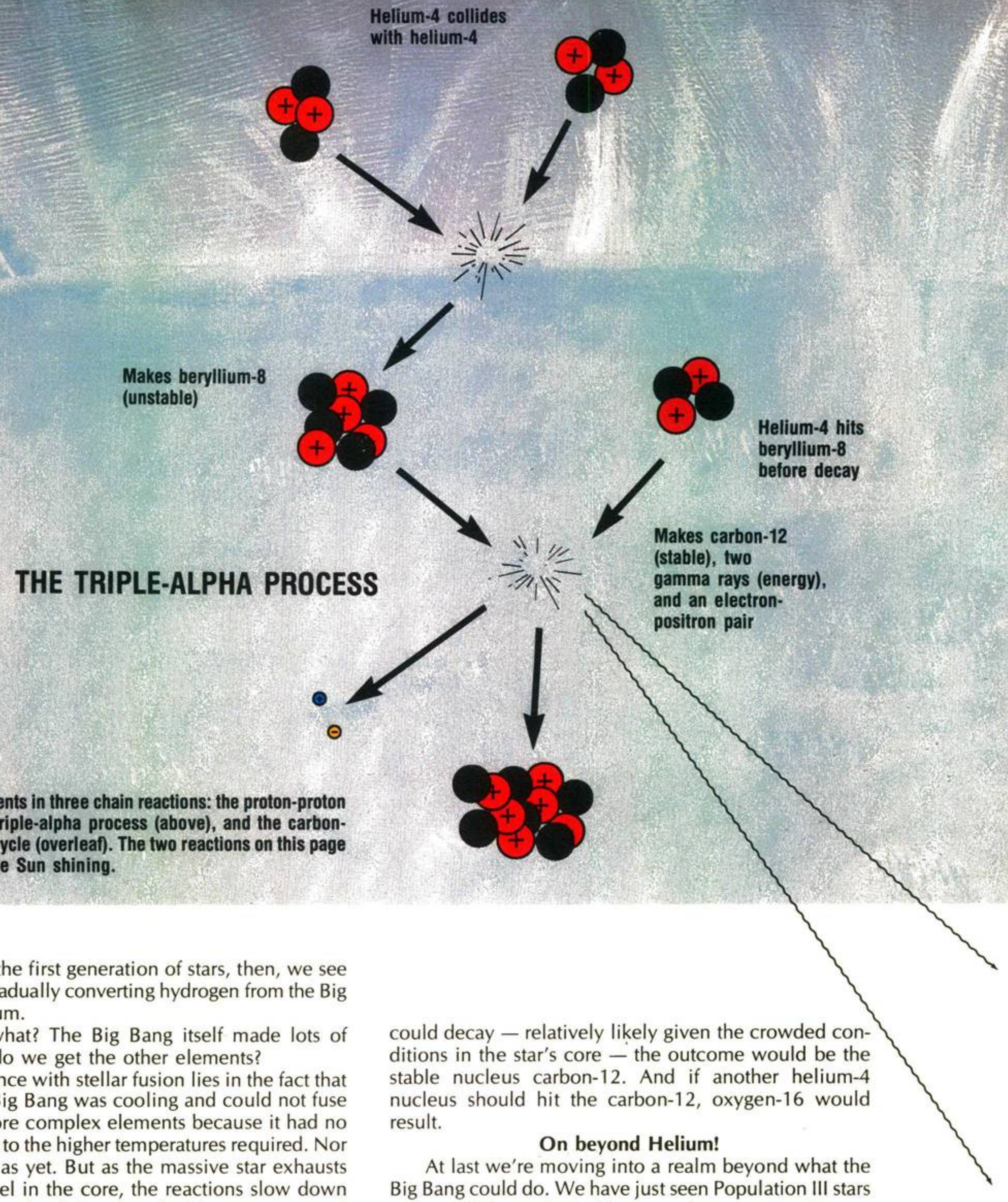
In overcoming the electrostatic repulsion, one of the protons gives up its positive charge by emitting a positron and thereby becomes a neutron. This neuton then combines with the other proton to make a deuteron. The positron is quickly annihilated by an electron and releases energy in the form of two gamma rays. A neutrino is also emitted but leaves the star without affecting anything on its way.

This sounds literally like a hit-or-miss process — hardly something to power a star with. But while only a tiny fraction of the protons reacts with one another, each proton experiences about 10 million collisions every second and even a smallish star like the Sun has about 10^{57} protons! While each such event may be rare, the sheer number of interactions is enough to keep the nuclear fires burning.

Let's return to the proton-proton chain reaction for a moment. Where the star once had two separate protons, it now has a deuteron. This was the crucial step in forming helium in the Big Bang. Fortunately stellar temperatures are not high enough to tear apart the deuteron. The deuteron quickly combines with a proton to form helium-3. Two helium-3 nuclei may then collide to form *helium-4, releasing two protons in* the process. If we keep careful track of the various bits, we find in the end that four protons have combined or *fused* to form one helium-4 nucleus and released radiant energy as a

MAKING ELEMENTS IN STARS

THE CREATION OF CARBON


Helium-4 collides with helium-4
Makes beryllium-8 (unstable)
Helium-4 hits beryllium-8 before decay
Makes carbon-12 (stable), two gamma rays (energy), and an electron-positron pair
THE TRIPLE-ALPHA PROCESS
+

Stars create elements in three chain reactions: the proton-proton chain (left), the triple-alpha process (above), and the carbon-nitrogen-oxygen cycle (overleaf). The two reactions on this page are what keep the Sun shining.

by-product. In the first generation of stars, then, we see proton fusion gradually converting hydrogen from the Big Bang into helium.

Well, so what? The Big Bang itself made lots of helium. How do we get the other elements?

The difference with stellar fusion lies in the fact that the gas in the Big Bang was cooling and could not fuse helium into more complex elements because it had no way to get back to the higher temperatures required. Nor can the star — as yet. But as the massive star exhausts its hydrogen fuel in the core, the reactions slow down and the pressure of radiation from inside cannot support the overlying layers as well as before. The star contracts a little, which increases the pressure in the core and raises the star's temperature to 200 million kelvins.

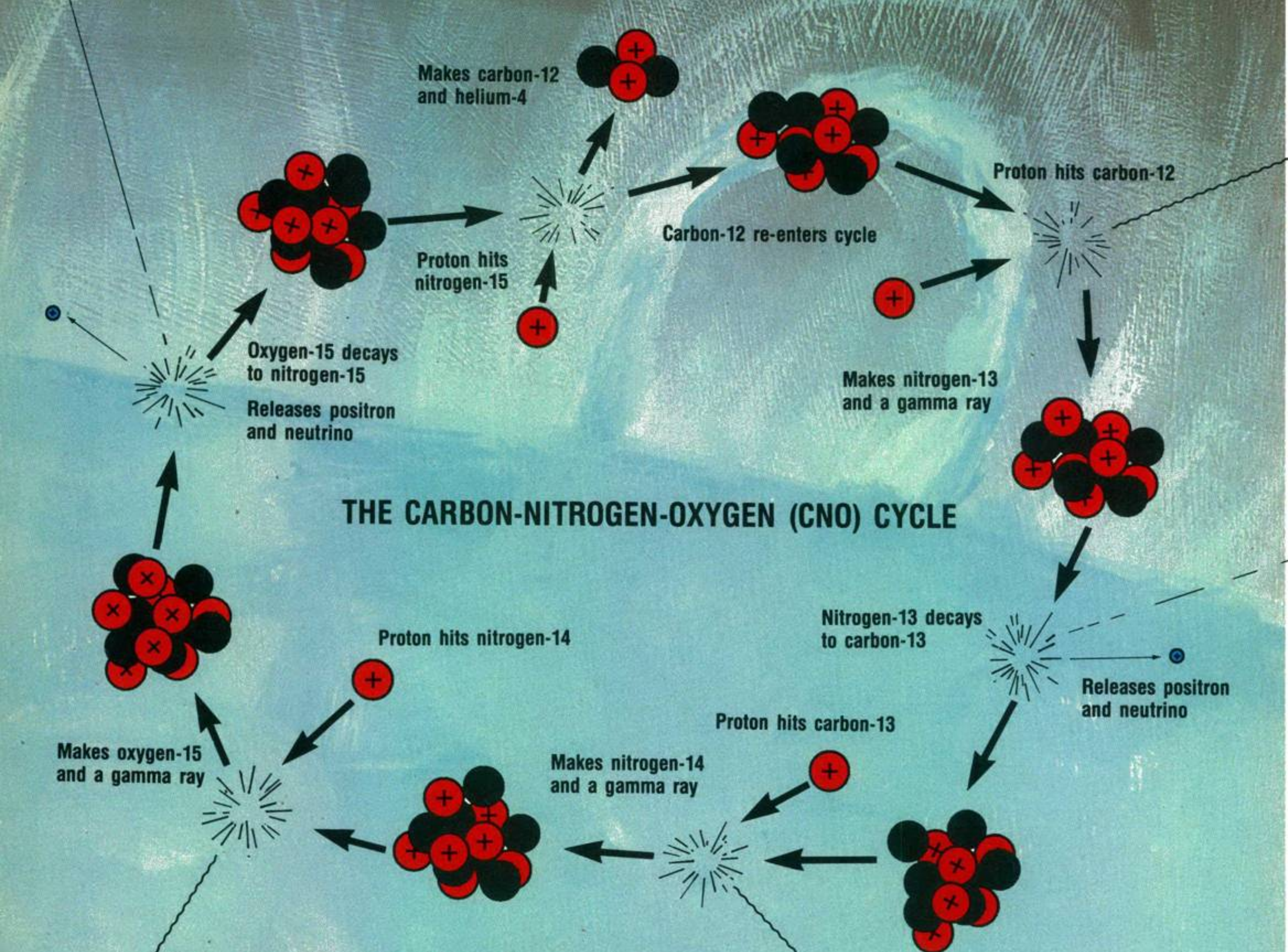
This lets helium-4 react with helium-4 to produce beryllium-8 in the so-called triple-alpha process. Atoms of mass number 8 are unstable, but if another helium-4 nucleus should interact with the beryllium-8 before it could decay — relatively likely given the crowded conditions in the star's core — the outcome would be the stable nucleus carbon-12. And if another helium-4 nucleus should hit the carbon-12, oxygen-16 would result.

On beyond Helium!

At last we're moving into a realm beyond what the Big Bang could do. We have just seen Population III stars — incredibly ancient objects no longer extant in our Galaxy — make the two most abundant elements (heavier than helium) that the Sun contains: oxygen and carbon. This step is also very important to you and me, because we are 65 percent oxygen and 18 percent carbon by mass.

The compressional heating by gravity continued as the helium reactions began to slow. The temperature of

HIGH-TEMPERATURE REACTIONS


Makes carbon-12
and helium-4
Proton hits carbon-12
Carbon-12 re-enters cycle
Proton hits
nitrogen-15
Oxygen-15 decays
to nitrogen-15
Releases positron
and neutrino
Makes nitrogen-13
and a gamma ray
Nitrogen-13 decays
to carbon-13
Releases positron
and neutrino
Proton hits nitrogen-14
Proton hits carbon-13
Makes nitrogen-14
and a gamma ray
Makes oxygen-15
and a gamma ray

THE CARBON-NITROGEN-OXYGEN (CNO) CYCLE

Carbon is the catalyst in the CNO cycle that powers large, hot stars. Four protons entering the cycle transform a carbon-12 nucleus through nitrogen and oxygen and back into carbon-12. Gamma-ray energy escapes and helium-4 is the "ash" left over.

the core soon climbed to over 800 million kelvins. Our Population III star is now moving more rapidly through its life. Where hydrogen burning was the dominant process for 2 million or 3 million years and helium burning spanned perhaps 200,000 to 300,000 years, the carbon reactions now powering the star ran through their cycles in less than a few centuries, in part because the reactions have more possible pathways.

For example, two carbon-12 nuclei can collide and release neon-20 and helium-4, or magnesium-24 and radiation, or sodium-23 and a proton. The reaction rates depend on the conditions in the star, but neon-20 is at least twice as likely to form as magnesium-24 and at least fifty times as likely to form as sodium-23.

Carbon burning, too, ran its course in the core, the star contracted, and the temperature rose once more. By this point, however, the photons flying around inside the core had enough energy to knock a helium-4 nucleus out of neon, which reduced it to oxygen. (In fact, neon-20 can be thought of as a helium-4 nucleus bound to an oxygen-16 nucleus.) Silicon-28 was created when one helium-4 nucleus collided with neon-20, which makes magnesium-24. When this in turn was hit by another helium-4 nucleus, silicon-28 resulted. And in oxygen and silicon we have the ingredients for one of the most common materials on Earth: sand.

Many of the reactions released neutrons. Because these neutrons carry no electric charge, they can penetrate the electrostatic repulsion of the nucleus to create new isotopes that may eventually decay to produce other elements. In this way, for example, silicon-28 can be converted (by a series of neutron captures and electron emissions) to chlorine-35, and magnesium-26 similarly becomes aluminum-27. The abundant neutrons available can produce all the elements up to and beyond uranium.

During most of a massive star's lifetime the nuclear reactions occur within a central core that is stirred by convection. In essence, it "boils" like a pot of soup on the stove. The elements are mixed between the core and outer regions of the star, which gives the star a quasi-homogeneous composition. Our prototypical Population III star was a stew of particles and nuclei swarming in layers of different temperatures.

As the star continued to collapse and heat up, a new phenomenon occurred in the high-temperature core. Gamma rays, which had been holding the star up with their radiation, began to collide with one another and transform into electron-positron pairs. (This is simply the inverse of the electron-positron annihilation reaction we saw back in the Big Bang.) But at this point in the star's life the change has drastic effects, because when an electron-positron pair is created, most of the gamma rays' energy is absorbed in the particles and little is left to maintain the supporting pressure. Quite literally, the star has the props kicked out from under it.

Unsupported, the star collapsed rapidly, heating up until oxygen-fusion began. For a very short time this yielded phosphorus, potassium, silicon, sulfur, chlorine, calcium, and titanium. But the outcome of oxygen burning is catastrophic — the star explodes. And we are lucky these stars died long ago in such a spectacular fashion, for otherwise the elements cooked up in their cores would remain there forever. Scattering the star's material into the galaxy at large passes on the bequest to later generations of stars.

Stars: Round Two

The explosion of the Population III star sent a blast rippling through the interstellar medium, and another generation of stars immediately began to form in the dense shell of gas behind the shock wave. These stars were enriched slightly by the elements (collectively called "metals") ejected by the dying Population III star. As this second stellar generation derives from the first, its members are said to belong to Population II.

Some theorists have suggested that Population II stars formed at the same time Population III did but had lower masses and evolved more slowly. In any case Population II stars exist today mainly as old, reddish stars found in globular clusters. Population II stars are defined by a small but distinct presence of metals in their spectra.

About forty years ago astronomers discerned another group of stars with a percentage of heavy elements that ran ten to a hundred times greater than in Population II stars. These stars — which include the Sun — were called Population I and are thought to be the youngest stellar population. (Most of the stars you see at night are Population I as well.)

Population I and Population II stars evolve along similar but not identical paths. Both the metal-poor Population II and the comparatively metal-rich Population I stars form by gravitational contraction, just as their Population III progenitors did. And the stars of the two populations evolve to become red giants, although the details differ because Population I stars have less hydrogen and more heavy elements than Population II stars.

The heavy elements affect a star in two principal ways. If a star has a high metallicity (it belongs to Population I, say), its stellar gas tends to be more opaque because the heavy elements provide many more ways to absorb photons. This means that Population I stars will be cooler and less luminous than Population II stars of the same mass. Being hotter, Population II stars will exhaust their nuclear fuel sooner than their Population I counterparts and will return processed heavy elements sooner to the interstellar medium.

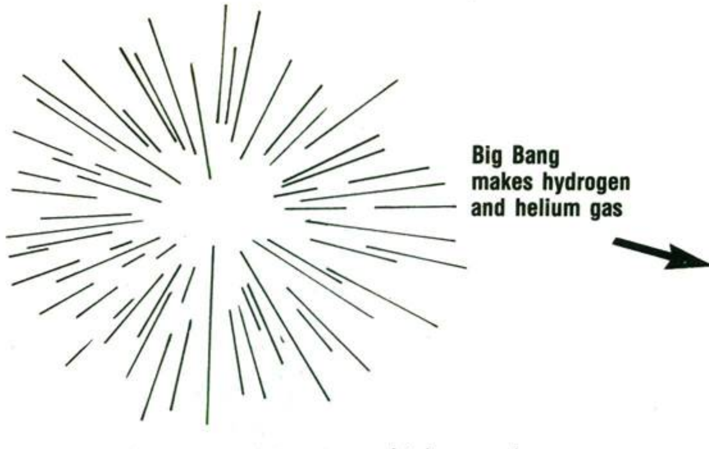
The second effect of metallicity is to alter the nuclear burning, which in turn modifies the structure and evolution of the star. A massive Population I star, for example, will derive more of its energy from the carbon-nitrogen-oxygen cycle of nuclear fusion, because it began its life with significant quantities of these elements.

The actual production of elements inside a Population II star goes ahead along the same pathways as its Population III forebear and the same elements are fabricated — up to a point. The most significant difference, however, is that Population II stars do not have to stop at fusing oxygen. The availability of pre-existing elements in their makeup lets them continue the chain reactions until they fuse silicon.

Stars with masses roughly equal to that of the Sun lack the ability to fuse anything beyond carbon. They evolve into red giants and shrug off their outer layers, which become planetary nebulae. (Their cores, now exposed to view, become solitary white dwarfs — small, highly dense, and hot stars.) In this way ordinary stars return their fused elements to the interstellar medium. But massive stars make a more dramatic exit. They can generate core temperatures high enough to carry the fusion reactions as far as iron.

But iron is a nuclear dead end. Instead of forming more massive elements when hit by a particle, iron simply breaks up into less massive nuclei. The result for a star is devastation on the grandest scale. When the reactions in the star's core reach iron, they stop immediately. With nothing pushing up from below, the star collapses upon itself in a few seconds. The outer layers fall onto the shrunken core and rebound explosively. Dying in a flash of light as bright as an entire galaxy, the star destroys itself as a supernova. But for a brief instant amid the explosion, element formation carries on, with small amounts of bismuth, gold, lead, uranium, and other elements being made and quickly scattered into space.

After such an explosion the more massive stars become black holes or neutron stars. Less massive stars — up to about seven times the Sun's mass — become white dwarfs. But some nucleosynthesis can still



continue, even in these highly evolved remnants.

For example, recent computer studies indicate that under certain conditions the accretion disk of gas that surrounds a black hole as an LP record surrounds a spindle can become hot enough to fuse lighter elements into heavier ones. Eventually the heavy elements may find their way into the polar jets thought to accompany all black holes with accretion disks and be ejected.

A white dwarf may also produce new elements if it has a companion star with loosely attached outer layers. The companion's gas is stolen by the white dwarf and ends up dumped onto the white dwarf's surface, where it may create densities and temperatures high enough to ignite new nuclear burning. Under the right conditions this can erupt in a supernova explosion bigger than those the more massive stars undergo. The result is the total destruction of the white dwarf star, but during the white dwarf's burning and explosion phases, substantial amounts of calcium, argon, sulfur, silicon, magnesium, and oxygen are produced.

Even as the blast wave from a supernova expands, new materials coalesce within it. Heavier elements — carbon, silicon, oxygen, calcium, and iron — clump together to make molecules from the debris of the explosion. Just as ice crystals form when water cools, heavy molecules condense into grains of dust. More massive than plain hydrogen and helium, they attract one another more than the two lighter elements, which thus ensures that enriched elements wind up in the material to make Population I stars.

Still nucleosynthesis does not end. The high-energy particles emitted in supernova explosions may become cosmic rays that roam the galaxy, constrained only by the galactic magnetic field. These can produce elements that cannot be formed in stellar interiors. For instance, if the less massive cosmic rays (protons and helium nuclei) interact with carbon, nitrogen, or oxygen in the interstellar medium, they can produce lithium, beryllium, and boron, three light elements too fragile to have survived inside stars.

Heavy Metal Stars

Population I stars and Population II stars evolve in similar ways. But the greater percentage of heavy elements in Population I stars allows a richer mix and more complex reaction pathways. Different isotopes and more heavy elements emerge than Populations III or II stars can achieve.

In stars with 1.5 times the mass of the Sun or more, the core temperature can reach 20 million kelvins or higher. This gives protons enough energy to penetrate the carbon nucleus and to begin the carbon-nitrogen-oxygen (CNO) cycle. This chain reaction starts with carbon-12 and creates in sequence nitrogen-13, carbon-13, nitrogen-14, oxygen-15, nitrogen-15, and finally arrives at carbon-12 again. Because the cycle begins and ends with carbon, this substance acts as a nuclear catalyst for the whole reaction. As in the proton-proton cycle the net effect is solely to produce one helium nucleus out of four protons — but great amounts of energy escape as by-products.

Because the CNO cycle depends strongly on temperature, it takes place in the hot cores of large stars. The energy it produces is carried outward in convective streams of hot gases, the turbulence of which churns the elements of the core into a relatively uniform consistency. Smaller, cooler, and less massive stars like the Sun, however, cannot generate temperatures high enough to use the CNO process to any great extent. Instead they rely on the proton-proton cycle. Less dependent on temperature, proton-proton reactions can occur throughout the core. This means the energy escapes, not by convection but by radiation, which leaves the star in chemically differentiated, unmixed layers.

Because less massive stars are unlikely to explode as supernovae, they contribute fewer heavy elements to the interstellar medium. Not only do their reactions stop at the lighter elements, but their differentiated layering keeps the heavier elements deep in the star, where they are less likely to be thrown into space when the star evolves to a red giant and sheds its planetary nebula.

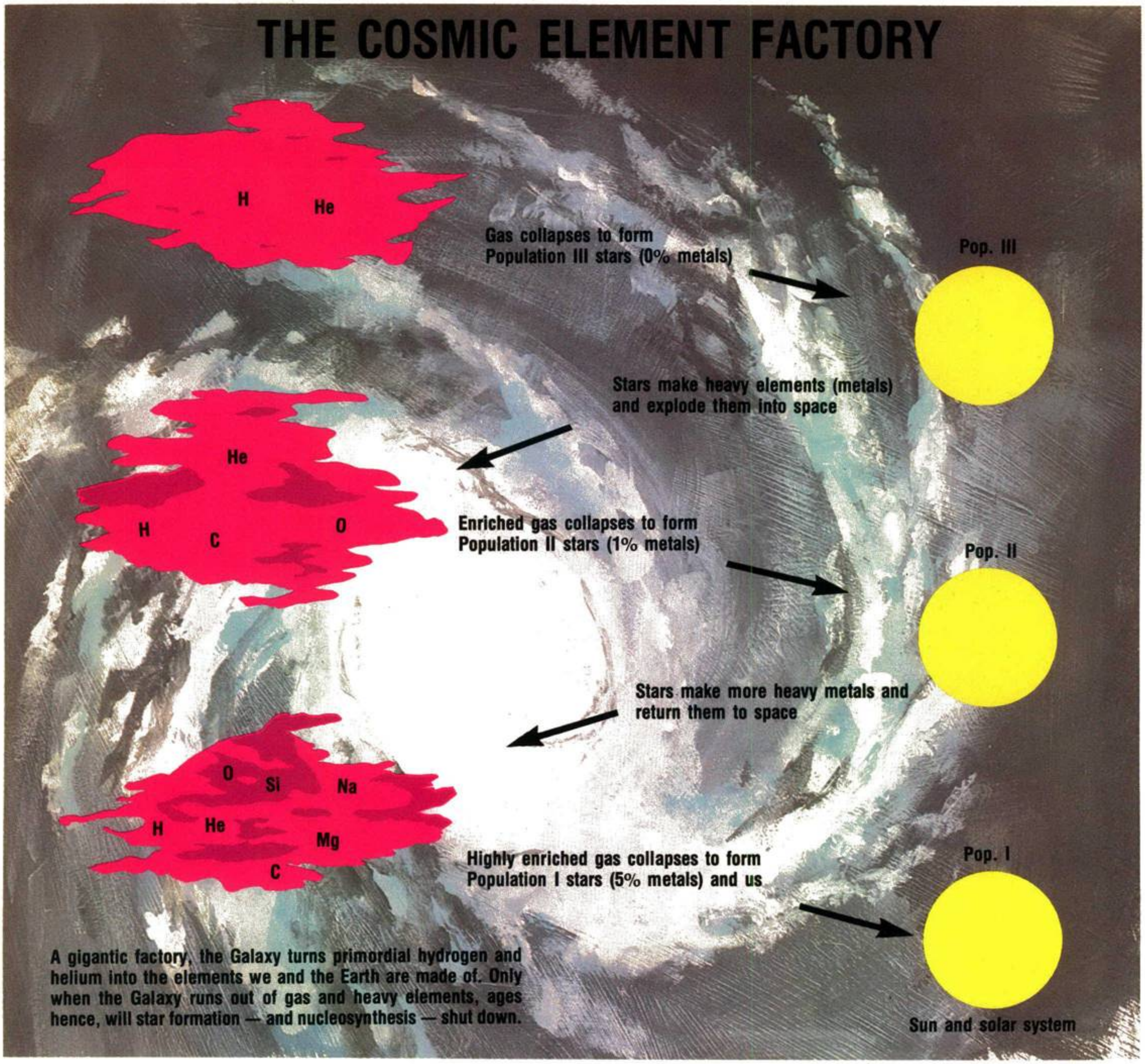
The Sun and Its System

Belonging to Population I, the Sun has inherited the output of the "cosmic factories" before it. Born about 5 billion years ago, the Sun began as a chemically homogeneous cloud of gas that slowly collapsed to form a rotating disk. The core of this solar nebula was the proto-Sun. If the cloud had formed right after the Big Bang, it would have been mostly hydrogen. This would have heated up quickly, begun to shine as a star, and swiftly driven off the remaining gas. No planets, no people. But because the stars of the Galaxy have been busily processing elements since then, the star-stuff that made the Sun took a different course.

Fortunately for us the heavy elements in the solar nebula were too massive to be driven away easily. Furthermore, they tended to clump together and thereby grew larger and heavier. Being opaque, the dust grains also absorbed radiation from the proto-Sun, which kept the temperature in the inner parts of the solar nebula high enough to "cook off" the hydrogen and helium that wasn't already locked up in the proto-Sun. This left an inner disk made up almost entirely of heavy elements.

Just as galaxies and stars grew out of instabilities, planets coalesced in the solar nebula and, once again, heavy elements made the difference for us. The radioactive decay of uranium, thorium, and potassium heated the mixture of iron and iron sulfides that permeated the early Earth. With Earth softened by heat, the heavy iron drained into the core of the planet, where the rotation set up electric currents and eventually a protective magnetic field. Other elements found their places and Earth was soon differentiated into a core, a mantle, and a crust. Volcanic activity began creating an atmosphere, and life changed it into what we have now.

The solar system presents a seemingly quiet and unchanging face toward us. Yet the Sun continues to evolve: already it has converted about half the hydrogen in its core to helium and has perhaps another 5 billion years of normal life left. But as its core becomes increasingly "poisoned" with helium, the reactions will slow and the temperature and density of the Sun will



THE COSMIC ELEMENT FACTORY

H
He
Gas collapses to form Population III stars (0% metals)
Pop. III
Stars make heavy elements (metals) and explode them into space
He
H
C
O
Enriched gas collapses to form Population II stars (1% metals)
Pop. II
Stars make more heavy metals and return them to space
O
Si
Na
H
He
Mg
C
Highly enriched gas collapses to form Population I stars (5% metals) and us
Pop. I
Sun and solar system

A gigantic factory, the Galaxy turns primordial hydrogen and helium into the elements we and the Earth are made of. Only when the Galaxy runs out of gas and heavy elements, ages hence, will star formation — and nucleosynthesis — shut down.

increase under gravity's incessant pull.

The heat from this contraction will cause the Sun to swell and become a red giant. In those far-off days the growing Sun will engulf first Mercury, Venus, and then Earth. Deep in the Sun, helium will finally ignite, with carbon accumulating as "ash." For the Sun, carbon will be the end of the line because the Sun lacks enough mass to create the temperatures for carbon fusion.

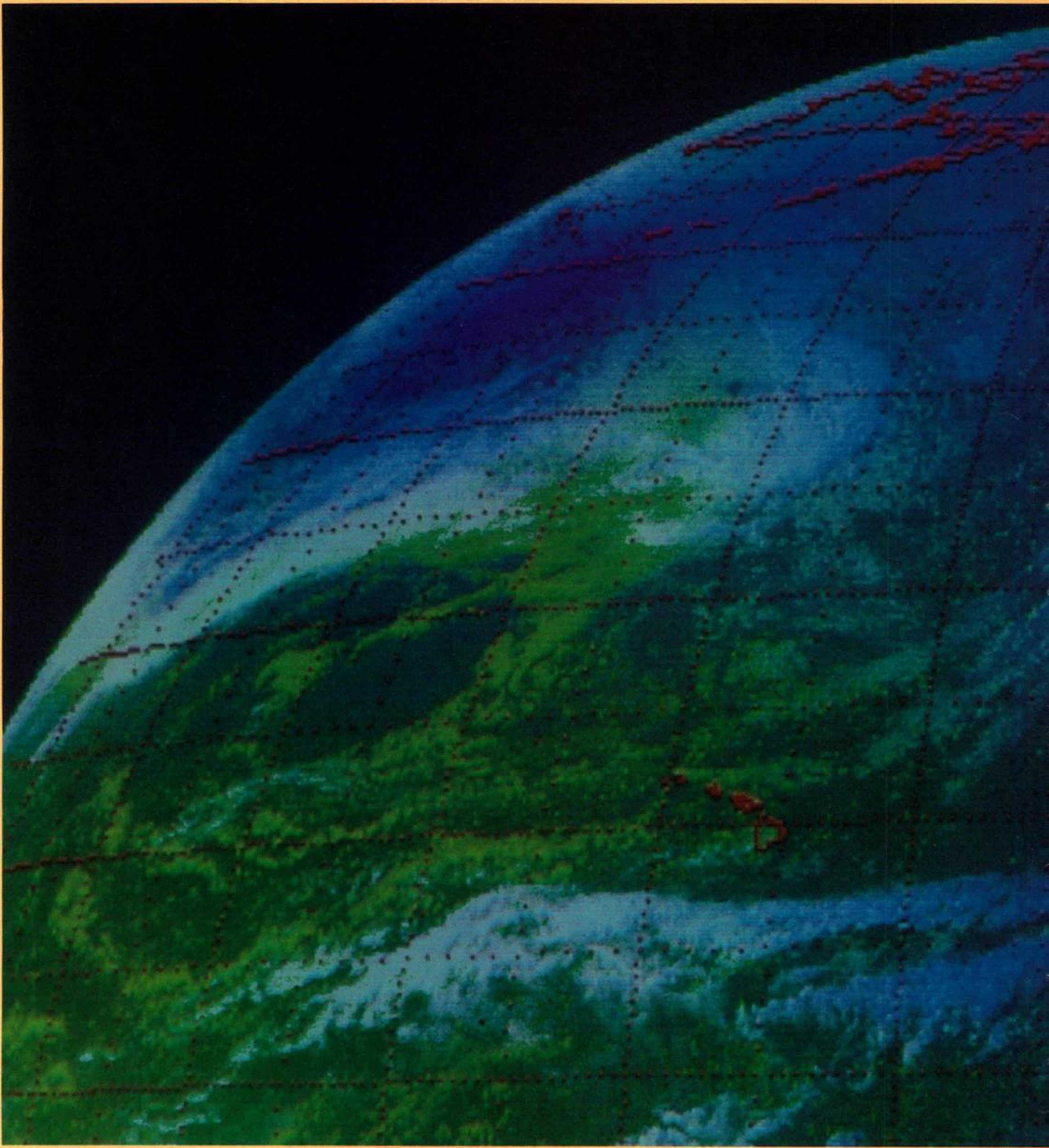
The Sun will shed its outer atmosphere, forming a hot shell of gas and leaving a slowly cooling white dwarf core of carbon. As the solar planetary nebula expands and dissipates, the Sun will pay back its birth dues by supplying a few heavy elements for new generations of stars.

In principle, stellar recycling can continue indefinitely, with the residue becoming ever richer in heavy elements. In practice, however, each loop through the cycle leaves about a third of the mass of the star trapped in some stellar remnant — white dwarf, neutron star, or black hole — where it is lost to further processing. Unless something intervenes, the universe will eventually run down from a lack of material to make new stars and planets. The far distant future, therefore, will behold a universe of dead stellar remnants and cool red stars, rich in elements synthesized from the primordial hydrogen of the Big Bang, untold ages before.

A grand chain — its links invisibly small — ties us to the Big Bang and runs through every atom of every one of us. □

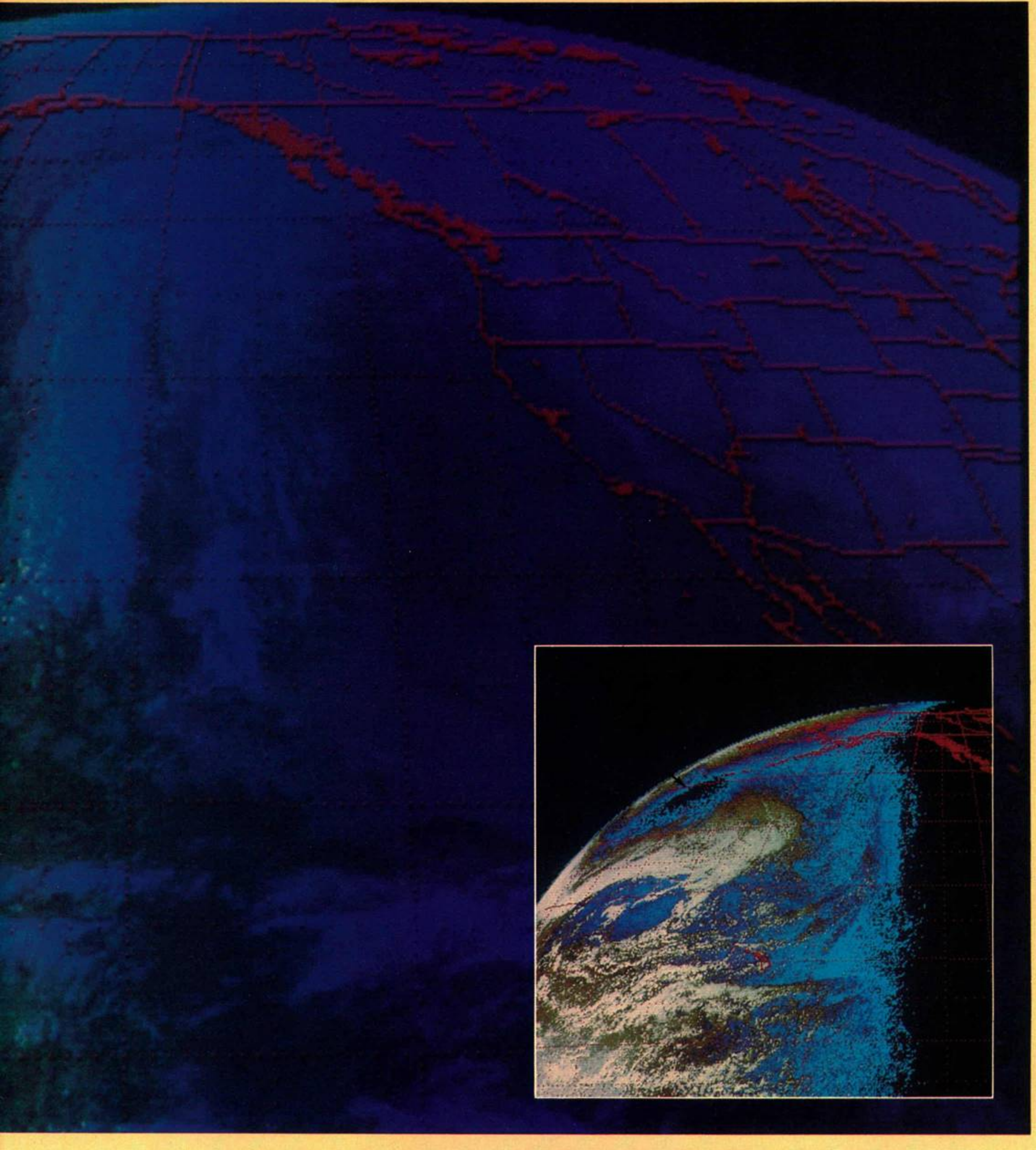
Gary Bennett, deputy director of the U.S. Department of Energy's Division of Special Applications, manages the department's radioisotope power source projects for space applications and has a doctorate in nuclear physics. His last article, "Voyage into the Third Dimension" in the May 1987 issue, described the Ulysses *solar probe mission.*

The 1988 Eclipse



SWEEPING ACROSS THE PACIFIC OCEAN, the shadow of the Moon was glimpsed on March 18 by the *GOES West* weather satellite as the eclipse shadow passed just south of the Aleutian Islands. Every half hour *GOES West* takes weather images that are used on the evening news from its orbit 20,000 miles above 135° west longitude. This picture, taken at 3:15 uni-

from Space



versal time, shows the eclipse shadow in visible and infrared light less than twenty minutes before it disappeared into the approaching night. The shadow appears slightly elongated because it is being projected onto the Earth's surface at an angle. The inset photo, which is a high-contrast, visible light version of the same image, pinpoints the Moon's shadow.

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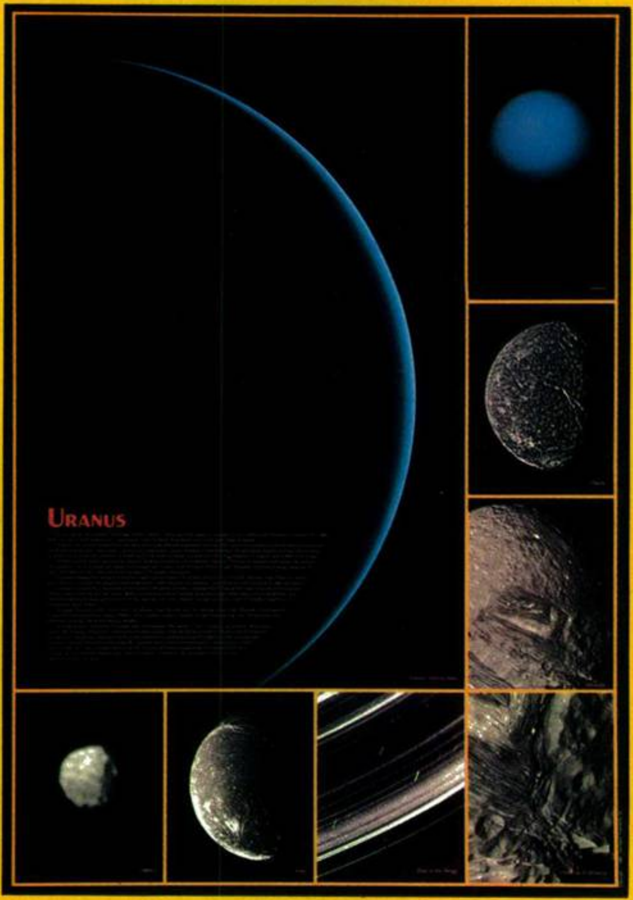

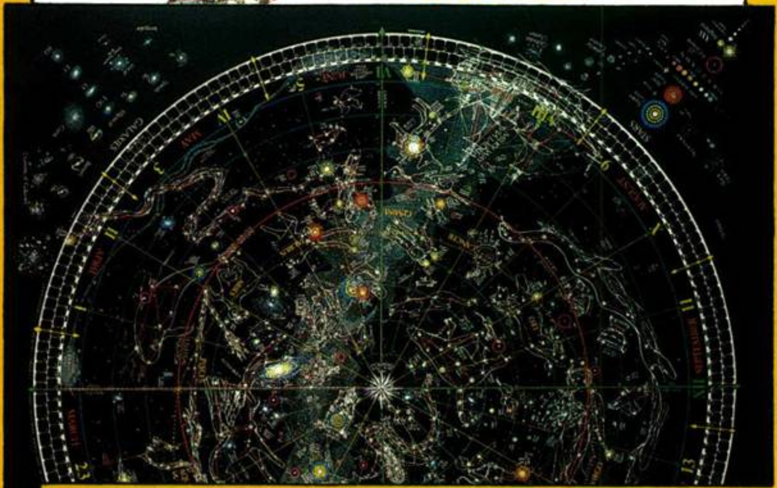

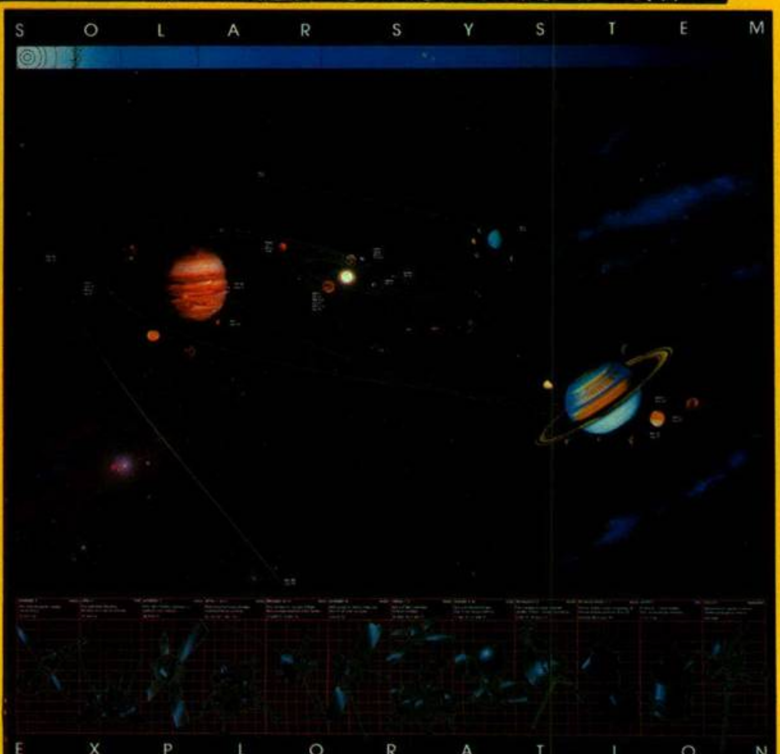

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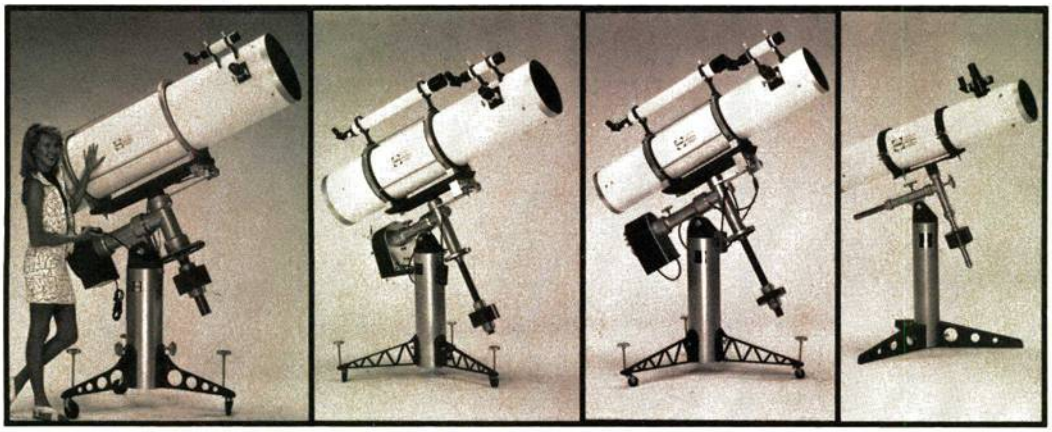

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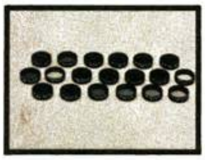

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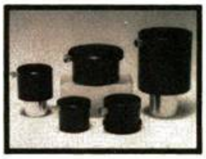

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The Pull of Planet X

Though the motions of Uranus and Neptune point to the existence of a tenth planet, researchers are uncertain that the planet they're searching for exists.

by Ken Croswell

In the outermost reaches of the solar system — beyond the asteroid belt, beyond Jupiter, beyond Saturn — the planets Uranus and Neptune slowly pursue their courses about the Sun. Billions of miles from the Earth, each world maintains a long orbit and moves majestically upon it: Uranus circles the Sun only once every 84 years, Neptune once every 165 years. But all is not well with these remote planets.

"I think there is something affecting our observations of the outer solar system," says Kenneth Seidelmann of the U.S. Naval Observatory in Washington, D.C. Seidelmann used to be able to blame the deviations in the motions of Uranus and Neptune on another distant object — Pluto. Astronomers once believed that Pluto had a mass similar to that of Earth and that Pluto's gravity pulled Uranus and Neptune off course. Ten years ago, however, scientists discovered the startling truth: Pluto is actually five hundred times less massive than Earth, much too tiny to perturb either Uranus or Neptune. Yet discrepancies in the motions of Uranus and Neptune persist, which causes some astronomers to search for an unseen "Planet X" that lies far beyond Pluto.

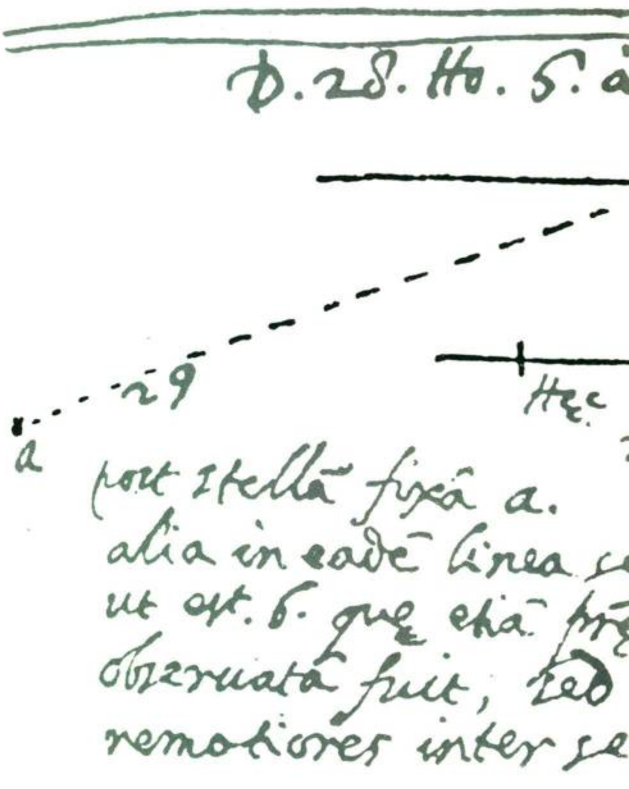
"The telescope we're using is our twin 8-inch aperture astrograph, which is currently down at our New Zealand station," says the Naval Observatory's Robert Harrington, who is leading the search for Planet X. "We think it's in the southern portion of the sky, in the region that goes through opposition in late summer and early fall."

The Discovery of the Outermost Planets

Harrington's search is not the first hunt astronomers have made for an unseen world. Although Uranus was found by accident, deviations in the motions of the outer planets also motivated the searches that revealed both Neptune and Pluto.

William Herschel discovered Uranus on March 13, 1781, as he was looking at stars in the constellation Gemini. Herschel's discovery doubled the size of the known solar system: Saturn lies 9.5 astronomical units (AU) from the Sun, Uranus 19.2 AU. (One astronomical unit equals the distance from the Sun to Earth — 93 million miles.) Because Uranus is farther from the Sun than Saturn is, it takes longer to complete an orbit. Saturn circles the Sun every 29.5 years, Uranus once every 84 years.

Immediately after the discovery of Uranus, astronomers wanted to calculate Uranus' orbit and generate an ephemeris for the new planet. (An ephemeris specifies exactly where the planet will be at a given time in the near future.) To compute an accurate orbit for a planet, though, one must observe the planet over most or preferably all of its orbit. Because Uranus takes 84 years to circle the Sun, the planet would not complete a full orbit until 1865.



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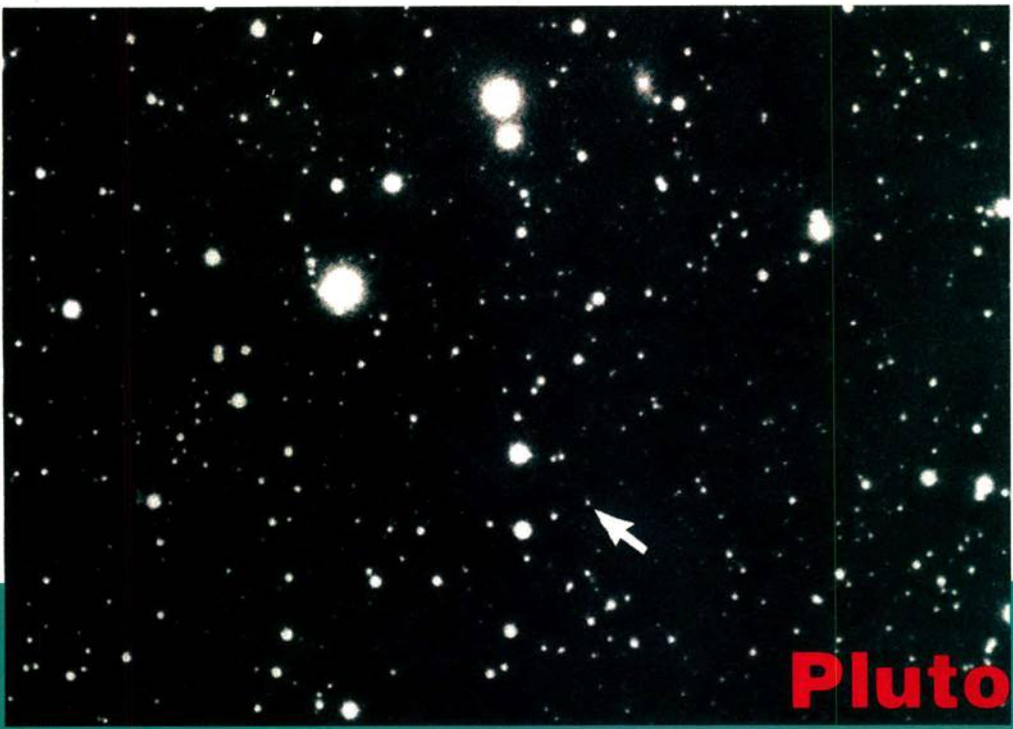
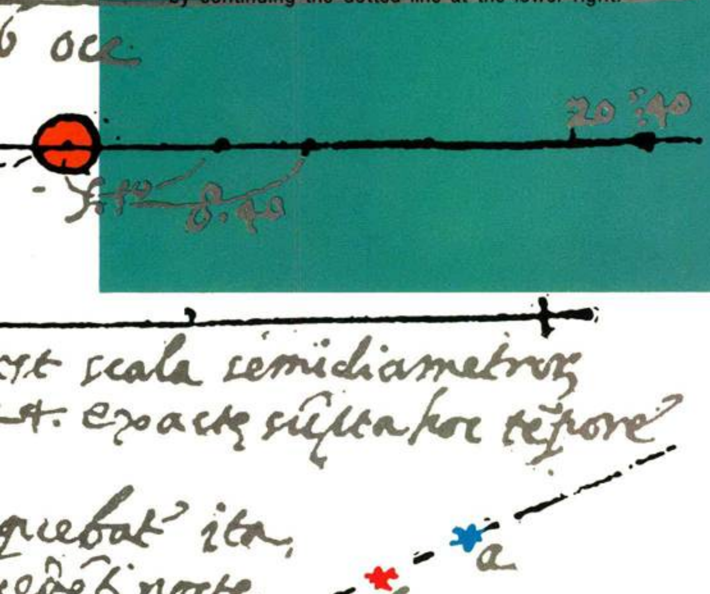
Scientists did not have to wait that long, however. Although Herschei discovered the planet, other astron-



CLYDE TOMBAUGH photographed a portion of the sky in Gemini and found Pluto in 1930. At the time some astronomers thought Pluto might be Planet X.

GALILEO INADVERTENTLY RECORDED NEPTUNE (below) while observing Jupiter (in orange) in 1613. The position of Neptune (in red) differs from the planet's predicted position by 51 arcseconds. Was this merely an inaccurate observation or does it imply that something tugged on the planet, causing it to deviate from its normal path? Because he didn't have room on the page to draw Neptune's angular distance from Jupiter to scale, Galileo indicated Neptune's position from a known star (in blue) by continuing the dotted line at the lower right.



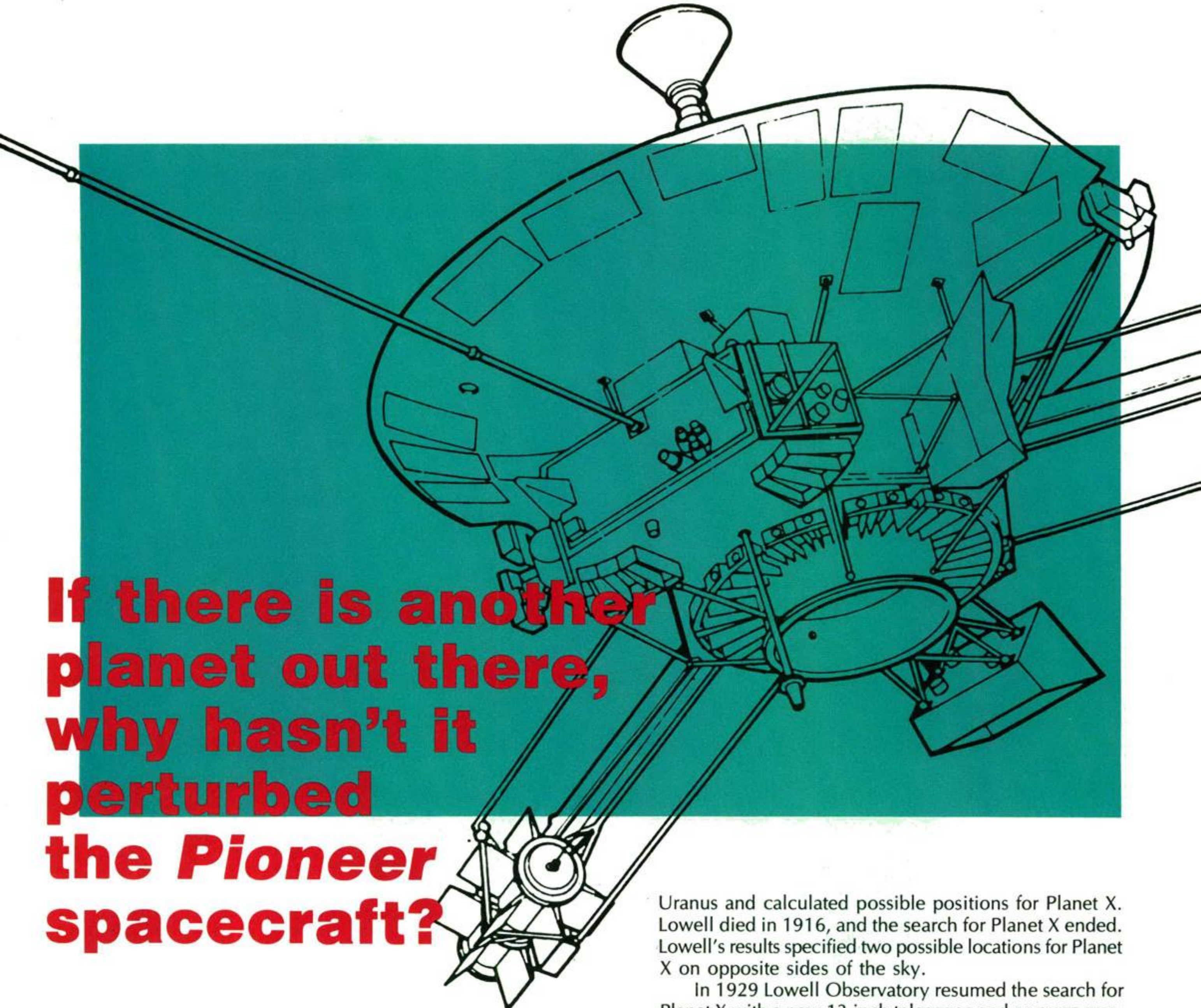
Pluto was thought to be Planet X but it was not big enough to disturb Neptune.

omers had recorded the position of Uranus prior to his discovery, but all mistook Uranus for a star. John Flamsteed was the first. He observed Uranus on December 23, 1690 — more than ninety years before Herschel identified Uranus as a planet.

Armed with this and other prediscovery observations, astronomers calculated the orbit of Uranus and generated an ephemeris for the planet. But Uranus refused to follow the predicted course. The planet's observed position always varied from its predicted one. Differences between a planet's predicted position and its observed position are called *residuals*, and the residuals for Uranus were far too large to attribute to observational error. By the 1820s astronomers simply threw out prediscovery observations of Uranus because no orbit could satisfy both the old observations and the new. New calculations were made, but Uranus still did not follow the predicted orbit. At their worst the Uranus residuals grew to over 100 arcseconds. (One arcsecond is 1/3,600 of a degree.) Furthermore, the newly calculated orbit meant that Flamsteed and other prediscovery observers had made huge errors — in some cases greater than 60 arcseconds.

The solution to the Uranus problem was simple: An unseen planet must be orbiting the Sun beyond Uranus and pulling Uranus off its predicted course. In 1845 and 1846 English astronomer John Couch Adams and French astronomer Urbain Leverrier analyzed the Uranus residuals and independently predicted the unknown planet's position. On September 23, 1846, German astronomers Johann Galle and Heinrich d'Arrest discovered the planet right where Adams and Leverrier said it would be, in the

If there is another planet out there, why hasn't it perturbed the *Pioneer* spacecraft?



constellation Aquarius. The planet, named Neptune, lay 30 AU from the Sun.

Uranus was an accident, Neptune an inspiration. Its position pinpointed prior to its actual discovery, Neptune convinced astronomers that still more distant planets could be found — not by searching the entire sky but by examining the motions of those planets already known to exist.

In the early twentieth century, American astronomers Percival Lowell and William Pickering independently sought to duplicate the feat that had made Adams and Leverrier famous. Both believed a planet lay beyond Neptune. Lowell gave the unknown planet the name we still use today — Planet X. Pickering called his unseen world Planet O. Though Lowell was more persistent, Pickering was more prolific: in addition to Planet O, he also proposed Planets P, Q, R, S, T, and U.

Lowell started searching for Planet X in 1905, before Pluto's discoverer was even born, and had his observatory in Flagstaff, Arizona, take photographs of the sky. From 1910 to 1914 Lowell analyzed the motion of Uranus and calculated possible positions for Planet X. Lowell died in 1916, and the search for Planet X ended. Lowell's results specified two possible locations for Planet X on opposite sides of the sky.

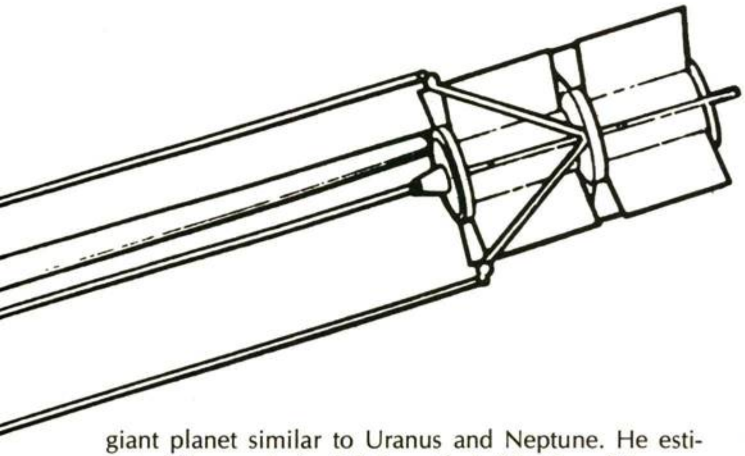
In 1929 Lowell Observatory resumed the search for Planet X with a new 13-inch telescope and a young amateur astronomer at the telescope's helm. Clyde Tombaugh took photographic plates of the sky and searched them for moving objects on a blink comparator. This device allows an astronomer to view two plates of the same part of the sky taken on different nights. In the comparator's eyepiece, stars remain fixed, but any moving object — planet, asteroid, or comet — appears to jump from one position to the other.

In January 1930, after searching for nearly a year, Tombaugh exposed plates from the constellation Gemini, one of the two regions where Lowell had thought Planet X was hiding. On February 18, Tombaugh blinked the plates and detected a faint image jumping back and forth. The distant world was Pluto — not far from where Lowell had predicted it.

The Innocence of Pluto

But Pluto is not Planet X. To perturb Uranus and Neptune, Pluto must be massive, because Pluto can affect the other planets only through its gravity. Today we know Pluto is so small that it cannot disturb the motion of Uranus or Neptune at all.

From the first, in fact, Pluto did not live up to Lowell's expectations. Lowell had thought Planet X was a



PIONEER 10* AND *PIONEER 11 are still following their respective courses out of the solar system in opposite directions. The spacecraft would be quite sensitive to the gravitational influence of any planet in the ecliptic.

giant planet similar to Uranus and Neptune. He estimated its mass to be 6.7 times that of Earth and its magnitude to be 12 or 13. But Tombaugh immediately noticed that Pluto was faint — only 15th magnitude. Furthermore, astronomers found that Pluto was so small they could not even discern its disk. Based on Pluto's faintness and smallness, astronomers believed the distant world had a mass no greater than that of Earth.

In 1968 astronomers analyzed the motion of Neptune and sought to determine Pluto's mass by observing Pluto's effect on Neptune. These scientists concluded that Pluto had to be 0.18 Earth mass to account for the observed deviations in Neptune's motion. Three years later, using improved data for Neptune's orbit, astronomers further reduced their estimate of Pluto's mass to 0.11 Earth mass.

In 1976 we got our first hint at how tiny Pluto really is. University of Hawaii astronomers Dale Cruikshank, Carl Pilcher, and David Morrison observed Pluto and detected methane ice, which is bright and reflective. Yet if Pluto reflects most of the sunlight striking it, Pluto must be small in order to be so faint. Before the discovery of Pluto's methane ice, scientists believed Pluto was about the size of Mars; afterward, that it might be smaller than the Moon. Such a little world could hardly perturb the other planets.

In 1978 astronomers finally proved once and for all that Pluto is not Planet X: they determined Pluto's mass. As he was looking at photographs of Pluto, James Christy of the U.S. Naval Observatory discovered the image of a satellite orbiting Pluto. A satellite indicates a planet's mass because for a given separation between planet and satellite, the more massive the planet, the faster the satellite must move to keep from falling into the planet. Pluto's moon lies twenty times closer to Pluto than our Moon does to us, but it takes 6.4 days to circle Pluto. Pluto therefore has very little mass. Robert Harrington calculated the satellite's orbit and placed Pluto's mass at a mere 0.002 Earth mass — five hundred times less massive than Earth. In 1985 astronomers detected eclipses of Pluto and its moon. As seen from Earth, Pluto's moon began moving in front of and behind the world it circles. The longer the eclipses last, the bigger Pluto must be. After three years of studying the eclipses, astronomers now believe Pluto is very small — only about 1,400 miles across.

Pluto is tiny. It is not Planet X. It does not affect Uranus or Neptune. It does not affect anything at all, except its own moon. Pluto is an innocent bystander, arrested on the strength of circumstantial evidence for a crime it did not commit. The true culprit is still on the loose, because the deviations in the motions of Uranus and Neptune continue unabated.

The Case for Planet X

Just as the residuals of Uranus once convinced some astronomers of the existence of Neptune, so the residuals of both Uranus and Neptune today suggest that Planet X may exist. If Planet X does exist, its gravity must pull the outer planets from their predicted paths. The more massive Planet X is and the closer it lies to another planet, the more it pulls the planet off course.

To see just how far off course a planet is, astronomers must calculate a good orbit and a reliable ephemeris for the planet, and to do that, astronomers must have observations of the planet over most or all of its orbit. Unfortunately, the farther a planet is from the Sun — and the closer it comes to Planet X — the longer it takes to revolve. Uranus circles the Sun every 84 years, Neptune every 165, and Pluto every 248. Of the three, Uranus should be in the best shape because it has completed 2.5 orbits since Herschel discovered it in 1781 and 3.5 orbits since Flamstead first observed it in 1690.

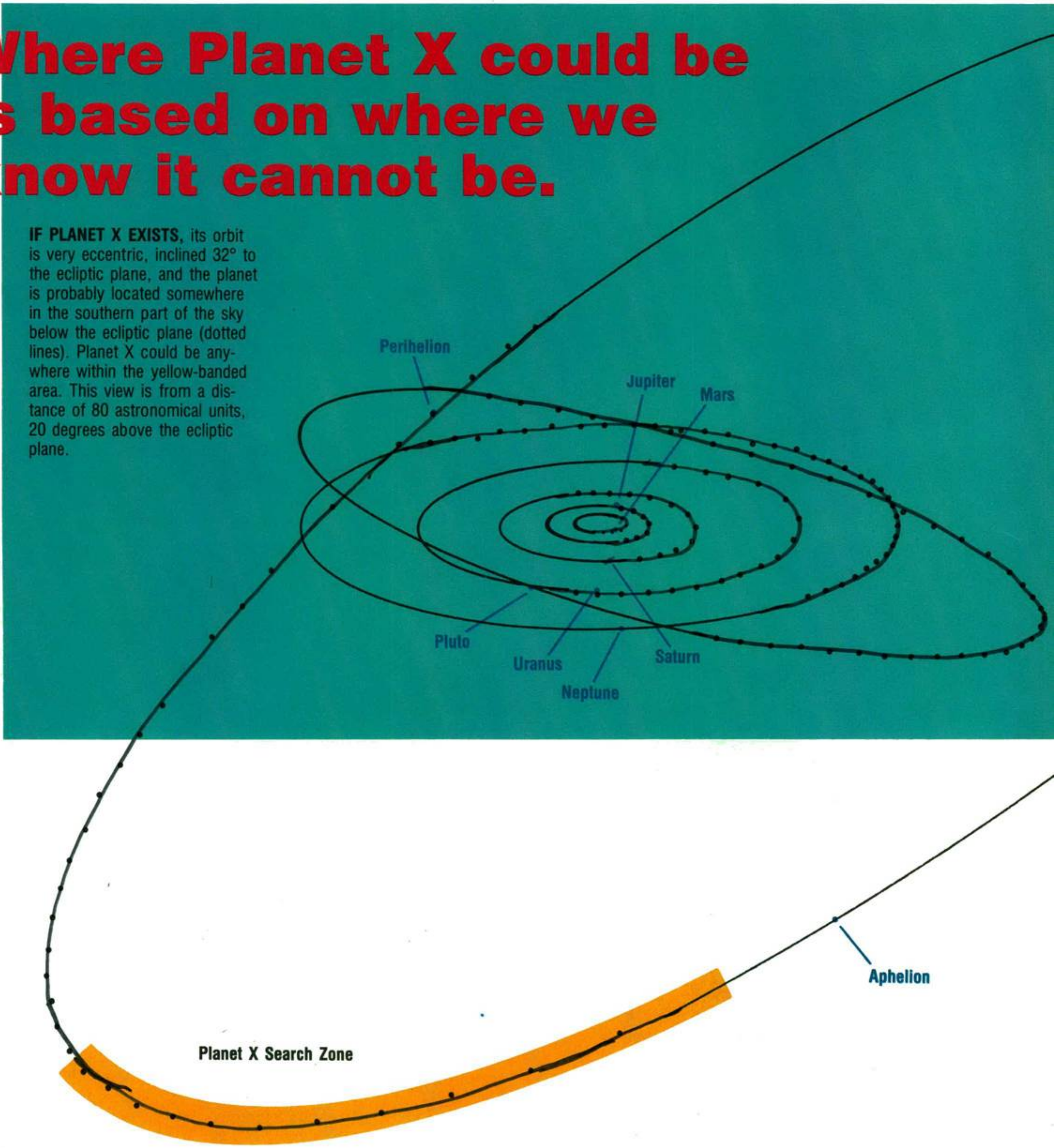
But, said Kenneth Seidelmann, "we cannot fit all the observations since discovery with a single ephemeris." Instead, Seidelmann has thrown out the observations of Uranus made prior to 1900 — just as nineteenth-century astronomers had to throw out observations of Uranus made before 1780.

"We had to do something," said Seidelmann. "Our requirement is to provide an accurate prediction ephemeris. If your ephemeris is running off at the current time, obviously you've got a problem as far as the prediction ephemeris is concerned." Dismissing the pre-1900 observations of Uranus "seemed like the best option as far as providing a prediction ephemeris — in fact, the only one that worked."

Neptune is potentially the most useful planet. It is more vulnerable to the influence of Planet X, because it lies a billion miles farther from the Sun than Uranus does. But with a period of 165 years, Neptune has not yet completed a full orbit since its discovery. So far Neptune has covered 86 percent of its orbit since 1846; it will return to its point of discovery in 2011.

"We can fit the observational data for Neptune," said Seidelmann. But in the past, Neptune has parted company with the calculated orbit about ten years after the ephemeris is computed. "We can't tell you why," says

Where Planet X could be is based on where we know it cannot be.



IF PLANET X EXISTS, its orbit is very eccentric, inclined 32° to the ecliptic plane, and the planet is probably located somewhere in the southern part of the sky below the ecliptic plane (dotted lines). Planet X could be anywhere within the yellow-banded area. This view is from a distance of 80 astronomical units, 20 degrees above the ecliptic plane.

Seidelmann, who is not optimistic that the current ephemeris, introduced in 1984, will fare any better.

The ephemeris is in far more serious trouble if prediscovery observations of Neptune are correct. In 1795 French astronomer Joseph Lalande was compiling a major star catalog. He observed thousands of stars and recorded their positions. On May 8, 1795, while observing stars for his catalog, Lalande recorded the position of an object where no star lies today. Two nights later, on May 10, he recorded the object's position again. He noticed that the May 8 measurement did not agree with the one from May 10. Lalande threw out the first, kept the second, and thereby missed discovering what we now know is the planet Neptune.

"The current ephemeris cannot fit the Lalande prediscovery observations of 1795," said Seidelmann. Lalande typically measured the positions of stars to an accuracy of 2 or 3 arcseconds. Yet his May 8 observation of Neptune differs from the ephemeris by 12 arcseconds, and his May 10 observation is off the ephe-

Possible Orbital Elements of Planet X

Perihelion	August 6, 1789
Semimajor Axis	101.2 AU
Eccentricity	0.411
Argument of Perihelion	208.5°
Longitude of Node	275.4°
Inclination	32.4°

meris by 13 arcseconds.

Lalande's are the best prediscovery observations yet known, but they aren't the oldest. In 1612 and 1613 Neptune fell under the eye of one of the greatest astronomers of all — Galileo Galilei. Not only are Galileo's observations the oldest we have, but they are also the only other prediscovery sightings we presently know about. Although much less accurate than Lalande's, Galileo's observations may — or may not — provide further evidence that Neptune was far off course.

Lalande's observations of Neptune have been known almost since the planet's discovery, but Galileo's are a recent find. In 1979 Steven Albers published a list of mutual occultations of the planets. He found that Jupiter occulted Neptune in January 1613, just three years after Galileo had discovered the four large moons of Jupiter. In 1980 Charles Kowal, now with the Space Telescope Science Institute, and Stillman Drake of the University of Toronto searched Galileo's notebooks and discovered that the Italian astronomer had recorded the position of Neptune twice. On December 28, 1612, Galileo sketched not only Jupiter and its moons but also the planet Neptune some distance away. A month later, on January 28, 1613, he recorded Neptune again, along with a star now known as SAO 119234. His notes read: "Beyond fixed star 'a' [SAO 119234], another followed in the same straight line; this is 'b' [Neptune], which was also observed on the preceding night, but they [then] seemed farther apart from one another." Galileo not only observed Neptune but detected its motion as well.

Neptune was so far from Jupiter the night Galileo first saw it that his position in late December is certainly not reliable. But Neptune was very close to SAO 119234 a month later, and Galileo's position for the planet on January 28, 1613, differs from the ephemeris by 51 arcseconds. In their discovery paper Kowal and Drake suggested that the January position might be trustworthy.

"I am very skeptical about that now," says Kowal. "I wouldn't go ahead and use that observation as a definite point. It's just not safe." Although Galileo usually recorded the positions of the Jovian moons to an accuracy of about 10 arcseconds, he was far more interested in them than he was in "stars" like Neptune.

Jupiter and Neptune met one another a century later in the constellation Pisces. According to Albers' calculations, Jupiter occulted Neptune in September 1702, but no one has yet uncovered any observations of Neptune made at that time. "As far as I know, no one has even searched, which is very disappointing," says Kowal. "Somewhere, in some observatory archives, there must be an observation of Jupiter and Neptune on those dates in 1702." Even one such observation could provide crucial evidence either for or against the existence of Planet X.

Although the residuals of both Uranus and Neptune suggest the existence of an additional planet in the solar system, those of Pluto can't. "We can fit an orbit through the observations of Pluto," said Seidelmann, "but it's like fitting to a shotgun pattern. So I can't say there are any problems with the observations of Pluto, because they don't cover a long enough period nor are they accurate enough to indicate a problem." Seidelmann notes that Pluto has completed only a quarter of its orbit since Tombaugh's discovery in 1930. Furthermore, Pluto is faint, so observations of its position are less reliable than those of Uranus and Neptune.

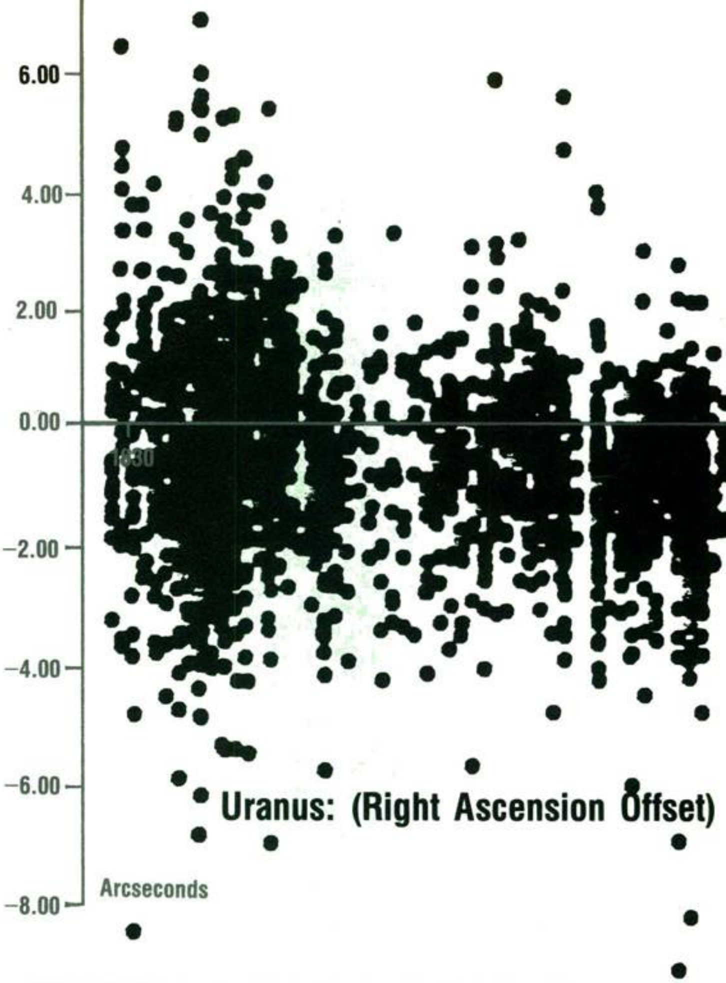
The Case against Planet X

While the problems with Uranus and Neptune may argue for Planet X, the motions of spacecraft traveling in the outer solar system do not. In the last few years four spacecraft have traversed the asteroid belt and are now heading out of the solar system at high speed: *Pioneer 10, Pioneer 11, Voyager 1*, and *Voyager 2*. If Planet X exists, it should tug at them the way it tugs at Uranus and Neptune. So far, however, the spacecraft are on course.

"We see no anomalous accelerations," said John Anderson of the Jet Propulsion Laboratory in Pasadena, California. Anderson is tracking the motion of the two *Pioneer* spacecraft, which are heading out of the solar system in opposite directions. "If all I had were the *Pioneer* data, I would be inclined to drop the problem of Planet X, but there are very real anomalies in the orbits of Uranus and Neptune."

Anderson believes his results rule out the existence of any undiscovered planet as big as Uranus or Neptune, each of which has about fifteen times the Earth's mass. A Planet X smaller than about five Earth masses could still exist, he said, provided it lies far above or below the ecliptic — the plane of the Earth's orbit.

"It's very unlikely that it can be in the ecliptic," says Anderson, for both *Pioneer 10* and *Pioneer 11* themselves lie in the ecliptic and so would be quite sensitive to any planet located in it. Anderson will continue to track the *Pioneer* spacecraft and will also be looking at *Voyagers 1* and *2*. Unfortunately, both *Voyagers* are traveling in the same direction as *Pioneer 11*, so they may not provide much additional information.



DISPARITIES between the observed and predicted locations of Neptune and Uranus may indicate that another planet is disturbing the orbital motions of these two planets. These plots compare right ascension ephemerides for Uranus and Neptune (horizontal line) to the planets' observed positions (black dots). The large scatter in the oldest observations is due to the low precision of those measurements.

The negative results from the *Pioneer* spacecraft don't surprise Seidelmann. "When they said they were going to test Planet X against *Pioneer* observations, we said it wouldn't be in the right places to do that. They found out they couldn't detect Planet X. That's what we expected."

The residuals in the motions of Uranus and Neptune therefore stand as the sole evidence for Planet X. But Planet X is not the only plausible explanation for those residuals. Another possibility — albeit a rather unlikely one — is that our current knowledge of gravity isn't quite correct. Because astronomers use the law of gravity to compute the orbits of the planets, incorrect knowledge of that law would lead to incorrect calculations. Although it's an extreme solution to the problem, this alternative worked once before.

"This was the situation with Mercury in 1900," said Seidelmann. At that time the innermost planet was far from its predicted path. "The hypothesis was that there was a planet inside Mercury. There was even a claim of the discovery of the planet inside Mercury. They even named the planet inside Mercury." It was called Vulcan.

Except in the world of *Star Trek*, there is no planet Vulcan. Mercury was off its predicted course simply because the orbit computed for it did not take into account the effects of general relativity. General relativity is a modification of Newton's law of gravity; in the solar system the effects of general relativity are greatest nearest the Sun and perturb Mercury the most. Perhaps general relativity itself is not quite correct and for some reason fails to predict the proper courses for Uranus and Neptune.

Although a defect in our knowledge of gravity is always a possible alternative to Planet X, the hypothetical "death star" Nemesis is not. According to the theory, Nemesis is a small star that revolves around the Sun once every 26 million years in a very elongated orbit; when it reaches perihelion, it stirs up the Oort comet cloud and hurls comets toward the inner solar system. Many of the comets collide with Earth, producing massive death and destruction.

For a number of reasons Nemesis probably does not exist. For one, it journeys 2 or 3 light-years from the Sun at aphelion, where a passing star could easily tear it from the Sun's grasp. After all, the nearest star system to the Sun — Alpha Centauri — is only 4.3 light-years away. But even if Nemesis does exist, it is not responsible for the deviations in the motions of Uranus and Neptune. According to the few who believe in it, Nemesis is now near aphelion — far too distant to affect Uranus or Neptune.

Does Planet X Really Exist?

Planet X is therefore the simplest explanation for the residuals in Uranus and Neptune — *if* the residuals are truly greater than the observational errors allow. Except for the prediscovery observations of Neptune, the residuals are undeniably small — typically between half an arcsecond and an arcsecond. Should we believe the residuals? Are they bigger than the observational errors?

"Definitely," says Raynor Duncombe, who used to calculate ephemerides at the Naval Observatory and is now with the University of Texas at Austin. "These are *not* measurement errors; they're too systematic. There is some unmodeled force in the solar system that is causing this."

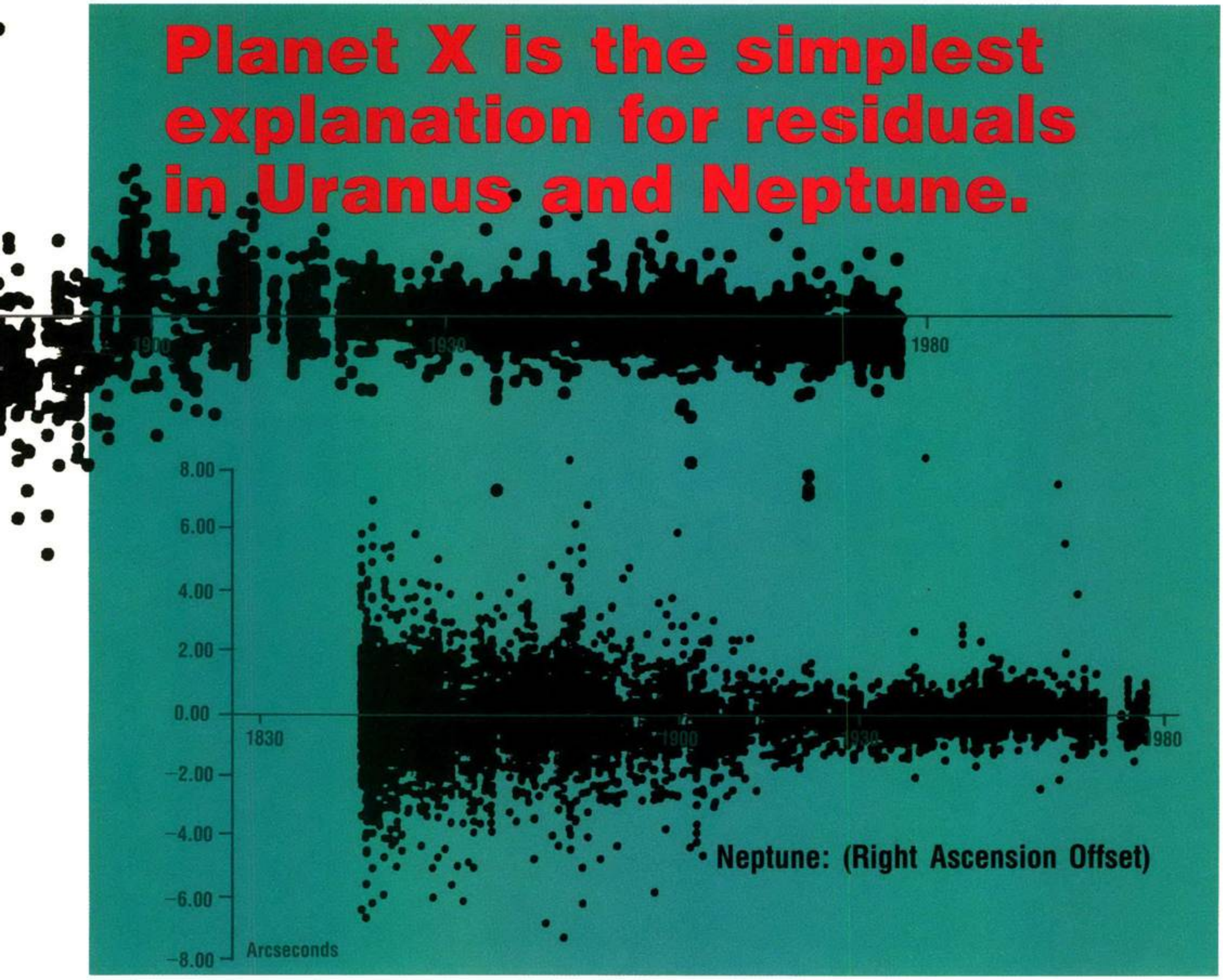
Says Seidelmann: "If you had asked me ten years ago, I was convinced that there was an observational problem. But, frankly, what we did was take the worst observations and go at them vigorously, and we reduced the uncertainty very effectively, but the systematic trend didn't change at all."

Not all astronomers agree, however. Says Brian Marsden of the Harvard-Smithsonian Center for Astrophysics: "Most of it's a bunch of nonsense. It is more likely that the residuals have some other explanation in some kind of observational error or instrumental error or systematic error. I think those have to be considered first, before we jump to wild conclusions about distant planets."

With the possible exception of Lalande's two observations of Neptune in 1795, Marsden believes there is absolutely no evidence for Planet X. "Lalande is all you've got," he says. "But was Lalande wrong? I have seen cases where people have made observations on two different nights, a couple of nights apart, and they've been systematically off."

"It's such a popular field," he laments. "As soon as you talk about it, everybody listens, the newspapers listen — they lap it up — and there's nothing to show for it yet, and I doubt that there will be. It seems to happen occasionally that people will get very carried away on certain kinds of astronomical topics. I don't know why — it's a psychological problem, not an astronomical one."

Planet X is the simplest explanation for residuals in Uranus and Neptune.



Says Anderson: "I'm relying on [the Naval Observatory's] analysis that you can't attribute the residuals in Uranus and Neptune to catalog errors or instrumental errors or personal errors on the part of the observer. I think they've done a pretty exhaustive search of all those error sources and ruled those sources of systematic error out. So I think they're quite convinced — and I agree with them — that there are definitely anomalies in those orbits."

Says Thomas van Flandern, formerly of the Naval Observatory: "To my way of thinking, there is no question about that. I think any objective look at the residuals by anyone would show that it's beyond what can be accounted for with all of the known sources of perturbation."

But, warns Harrington, "we're talking about residuals that are a whole heck of a lot smaller than anything that Adams and Leverrier had to work with. I think these residuals probably do genuinely stand out above the noise, but they're not what you would call incredibly conspicuous," he says. "It could still be just observational error." His cautious assessment is a bit ironic: Harrington is leading the search for Planet X.

The Search for Planet X

"I am confident enough that it's out there that I'm willing to spend a fair amount of my time and the Navy's money to look," says Harrington. "But I'm not so confident that I'm going to go out and make a major campaign to look for this thing."

Harrington isn't the first to search for planets beyond Pluto. After he discovered Pluto in 1930, Clyde Tombaugh continued his hunt for distant planets until 1943, looking farther and farther above and below the ecliptic. He concluded that no planet brighter than 16th magnitude exists in the region he investigated.

"It would have to have a pretty high inclination to be beyond the zone that I searched," says Tombaugh. His survey therefore backs up the *Pioneer* data that imply any Planet X must lie far from the ecliptic. "The one possibility might be in the region south of the summer Milky Way, south of the place where the Sun is at winter solstice, because I wasn't able to get as far from the zodiac there because of my restriction on latitude."

Harrington agrees. "I think the planet's in the south, and I think it's in the portion of the sky that we can get at opposition in summer and early fall."

Harrington bases his calculation on the residuals of Neptune rather than Uranus. "They're there in both planets," he says. "The problem we're having with Uranus is that even though we've got a good orbit for it, we don't in fact actually know the mass of Neptune terribly well. If I have to assume there are two planets out there — both

Some astronomers think Planet X may be in the southern sky.

IS PLANET X in this photo (left)? This portion of the search area, located in the tail of Scorpius, is rich in stars, which makes locating a 14th-magnitude planet difficult. Robert Harrington, who is heading up the search, blinks plates taken by observers in New Zealand (above).

with an unknown mass affecting Uranus — it gets completely impossible to tell how much perturbation is due to which planet. On the other hand, we don't have a complete orbit of Neptune yet, but we have a pretty good idea of what Uranus' influence on Neptune is," because the mass of Uranus is precisely known.

The mass of Neptune will also soon be known: in August 1989 *Voyager 2* will pass the planet, and Neptune's gravity will bend the spacecraft's path and allow scientists to deduce the planet's mass exactly. "That will be a *very* big help," says Harrington, who is looking forward to using the Uranus residuals in his hunt for Planet X.

Until then he is relying on the irregularities in Neptune's motion. Harrington believes Planet X has both a highly inclined and eccentric orbit. Just as Percival Lowell placed his Planet X in two opposite regions of the sky, so Harrington puts his unseen world in two different locations — one to the north, the other to the south.

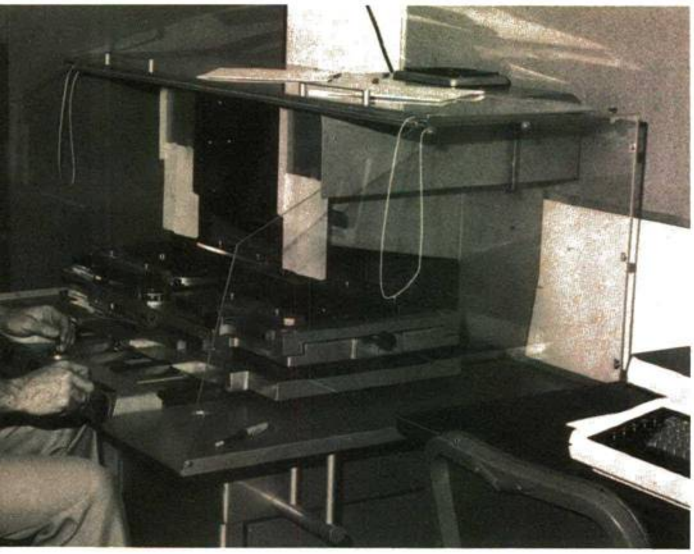
"Whenever you do a solution for a missing planet, there are always two solutions," he said. "It's exactly equivalent to how you can't tell at high tide whether the Moon is overhead or underfoot." Harrington believes that Tombaugh's thorough search rules out the northern solution, so he is looking south. An observer in New Zealand produces the plates that are then shipped to Washington, where Harrington blinks them.

"We don't have a very specific location because it's a very, very difficult thing to calculate," he says. "We kind of suspect that it was in the Milky Way back when Tombaugh was doing his search — that it was way down in the very southern Milky Way, down in Sagittarius. But we think it has now gotten out of the Milky Way."

Harrington's is not the only recent hunt for Planet X. From 1977 to 1984 Charles Kowal used the 48-inch Schmidt telescope at Palomar to "search for anything unusual" near the ecliptic, penetrating to 20th magnitude. By far the most unusual object he found was the far-off asteroid Chiron, which in many ways resembles Pluto. Chiron normally lies between Saturn and Uranus, but near perihelion it cuts inside the orbit of Saturn.

Of his search, Kowal said, "It did turn up asteroid Chiron and a few comets and a few nearby asteroids. But I decided that this was too much of a needle-in-a-haystack problem and that we really have to predict where the planet is before conducting much of a search for it."

If it really does exist, what might Planet X be like? "We keep coming up with masses on the order of two to five Earths," says Harrington. Planet X is therefore intermediate in mass between the largest inner planet — Earth — and the smallest outer planets — Uranus and Neptune. Most estimates place the planet at a distance between 50 and 100 AU from the Sun, which gives Planet X an orbital period between 350 and 1,000 years. Because of its size and distance, Planet X is probably around 14th magnitude — far fainter than Neptune but brighter



than Pluto was at the time of its discovery.

Like Pluto, Planet X may have a very strange orbit. The *Pioneer* data, Tombaugh's search, and Harrington's calculations all indicate that the orbit is highly inclined to the ecliptic. Furthermore, Harrington believes the orbit is eccentric as well. If so, it's in good company: the orbit of Pluto is also highly inclined and eccentric. Pluto's orbit makes an angle of 17 degrees with the ecliptic, and its eccentricity is so great that near perihelion Pluto lies closer to the Sun than Neptune does.

Pluto's small size and odd orbit suggest that Pluto may be an escaped moon of Neptune, an idea put forth by Issei Yamamoto in 1934, Raymond Lyttleton in 1936, and Gerard Kuiper in 1956. Unlike Pluto, Neptune has a very normal orbit — one that is both extremely circular and only slightly inclined to the ecliptic. Yet the planet's satellite system is chaotic: its large moon Triton circles Neptune backward in a decaying orbit, while its small moon Nereid has an extremely eccentric orbit about Neptune.

Ten years ago Harrington and van Flandern revived the hypothesis that Pluto is an escaped satellite of Neptune. They proposed that Neptune originally had at least three satellites — Triton, Nereid, and Pluto — when a massive planet nearly collided with Neptune. The intruder planet's gravity reversed the orbit of Triton, elongated the orbit of Nereid, and ejected Pluto from the system altogether. Harrington and van Flandern conducted numerical experiments to see what kind of planet would do the trick. They found that the planet must have a mass two to five times that of Earth and might now lie in an eccentric orbit — in other words, it would be a lot like Planet X.

"We think it's that planet," says Harrington. "That's one of the things that made all of this so interesting. We did that article back in 1978, and I thought we were doing it purely as a mathematical exercise — until the discovery of the satellite of Pluto, which revealed Pluto's mass and immediately made it obvious that Pluto wasn't the thing they were looking for back in 1930. And then somebody pointed out to me later that if you do the solution for the planet from the residuals of either Uranus or Neptune, you get something that looks very similar to what we were talking about for this interloper that produced Pluto."

The Joy of X

Should it ever occur, the discovery of Planet X would push back the frontiers of the solar system. Billions of miles distant, Planet X would give astronomers fundamental insight into how the planets formed around the Sun, because it would tell us what kind of planet can arise so far from the star it circles. The four planets closest to the Sun — Mercury, Venus, Earth, and Mars — are small, rocky worlds, and the four planets farthest from the Sun — Jupiter, Saturn, Uranus, and Neptune — are giant worlds with thick atmospheres. What would Planet X be like? A giant world like Uranus and Neptune? Or a type of planet not yet known to astronomers?

To answer these questions, astronomers would rush to determine the nature of Planet X. To measure its size, they would observe the planet through the most powerful telescopes in the world. To deduce its mass, they would look for satellites circling the planet. And to calculate its orbit, they would search old photographic plates for past images of the planet.

Planet X would surely excite the public as much as it would astronomers. Television news teams, magazine writers, and newspaper reporters would swarm over the observatory that discovered Planet X, interviewing — and interrupting — everyone in sight.

"Nobody around here in any level of the hierarchy has ever been confronted with the question of the protocol for announcing a discovered planet," says Harrington. "You never know what's going to happen."

As astronomers struggle to determine Planet X's mass and orbit, the public might well take part in the same debate that ensued following Pluto's discovery: what to name the new planet. It may be a difficult task, however, for there are now over four dozen known satellites and nearly four thousand known asteroids. The names of these objects cannot go to Planet X.

Consider the possibilities — and the problems. Suppose we want to name Planet X Minerva, the goddess of wisdom. It's asteroid number 93. Or how about Proserpina, Pluto's companion in the underworld? It's asteroid number 26. Or try Janus, the two-faced god. It's a satellite of Saturn. Even Cerberus — Pluto's dog — won't work: it's asteroid number 1865.

Whether such a debate ever occurs depends, of course, on whether or not Planet X exists. "The *Pioneer* evidence is weighing against it," says Kowal. But he is nonetheless impressed by the residuals in the motions of Uranus and Neptune. "I think that's fairly strong evidence." Does Planet X really exist? "I'd say — probably."

"We've been poking away at it ever since 1978, when we did the moon of Pluto," says Harrington. "We will continue to poke away at it as long as I still come up with what I think are reasonably good suggestions for where the thing might be."

And what does Pluto's discoverer think? "I just wish 'em luck," says Tombaugh. "They're in for a lot of hard work." ☐

A graduate student at Harvard University, Ken Croswell has written for Air & Space, Astronomy Now, *and* Space World. *He is also a contributing author to* Voyage through the Universe, *a series of astronomy books being published by Time-Life Books. His latest article for ASTRONOMY was "Does Barnard's Star Have Planets?" (March 1988).*

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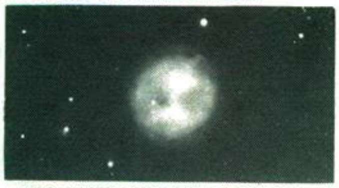

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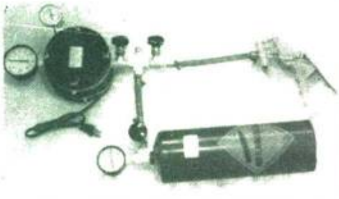

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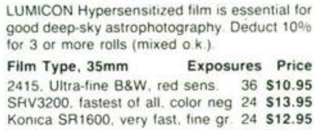

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The computer's sophisticated program (over 3000 lines of code) determines **everything** from an initial sighting of just two stars!

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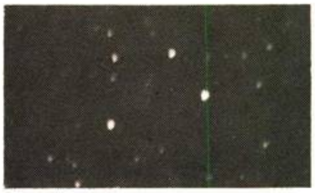

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This computer-designed LUMICON 2" lens reduces coma and flattens the field for both viewing and photography. It threads into LUMICON 2" EASY-GUIDERS for effortless installation. This lens is optimized for f/4.5 and reduces aberrations for f/3.5 to f/5 Newtonians. Off-axis images are much smaller, making off-axis guiding far easier and yielding round pinpoint star images in photos. Since star images are sharp over a full 2¼" circle, you can use medium format cameras in addition to 35mm cameras. This zero power lens does not change image scale, and all lens surfaces are multi-coated for highest efficiency. Although designed for photography you may also use this lens to improve image quality in wide-field viewing with low power eyepieces.

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Coma Corrector/Field Flattener lens

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Burhan's *Celestial Handbook*, Vol. I, II, III (Epoch 1950.0)	**$36.85**
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Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 21" OD, SUPER-FINDER base plate.

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1¼" Deluxe right-angle Super-Finder*	**$279**
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25mm Cross-hair 1¼" eyepiece (12X)	**$29**
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These adapters convert refractors and Schmidt-Cassegrain telescopes for 2" operation. They allow use of 2" accessories, such as the LUMICON 2" EASY-GUIDER for photography. They also allow use of 2" eyepieces and/or 2" star diagonal for viewing.

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1.8x Multiplier Lens

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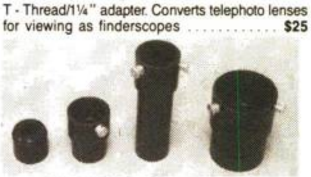

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These 48mm Filters thread into LUMICON EASY-GUIDERS and most 2" eyepieces. Use adapter for 1¼" eyepieces. AR Coated.

Filter:	**Bandpass**	**Trans**	**Price**
Ultraviolet	320-420nm	85%	**$35**
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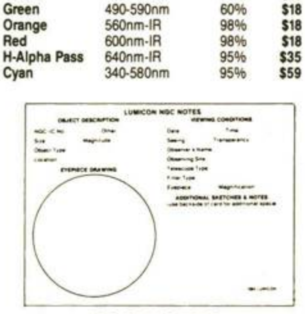
Green	490-590nm	60%	**$18**
Orange	560nm-IR	98%	**$18**
Red	600nm-IR	98%	**$18**
H-Alpha Pass	640nm-IR	95%	**$35**
Cyan	340-580nm	95%	**$59**


LUMICON NGC NOTES
OBJECT DESCRIPTION
VIEWING CONDITIONS
EYEPIECE DRAWING

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THINKING TELESCOPES

Research on active, spotted, and rapidly rotating stars is being transformed by small, computerized telescopes.

by Richard Berry

They're small, they're efficient, and they're fully automated. They turn themselves on, work all night, and shut down at dawn. They work while the astronomer sleeps. They're a new generation of small automated telescopes, and they're revolutionizing how astronomers do astronomy.

"These telescopes don't *just* work all night," says astronomer and automated telescope user Douglas Hall. "They work all night after night after night after night, on huge, long, monotonous, ongoing, rudimentary, methodical observing programs that numb the brains of living observers. And they don't get bored and they don't quit." The Vanderbilt University astronomer has been an automated telescope user for over four years.

Amateur astronomers engineered the first practical automated photoelectric telescopes — APTs for short. Professional astronomers have now begun to realize the gains in scientific output that automation offers, especially for research into the nature of variable stars. That's because a small, automated telescope operating at an excellent site can make more observations faster than a human being could and for a very low cost.

These small telescopes carry photoelectric photometers to measure the brightness of stars. Brightness is a quantity astronomers can measure directly, and it's fundamental to almost everything we know about celestial bodies.

Photometry is an inefficient way to use telescope time, however. While an astronomer is aiming the telescope, climbing a ladder, flipping levers, turning filter holders, and writing down brightness readings, starlight and telescope time are wasted. In sharp contrast, automated telescopes zip from star to star, lock onto each new star in seconds, flip filters in split seconds, and then drink in starlight. "We should let the astronomer think about science," says David Crawford of Kitt Peak National Observatory, "instead of making him part of the telescope control system."

Amateurs Pioneer the APT

APTs are the brainchild of amateur astronomers who wanted to try doing "real astronomy" and a professional astronomer who enlisted amateurs to take photometric data for him.

Doug Hall discovered amateur astronomers because he studied RS Canum Venaticorum stars, stars that vary because of large "starspots" on their surfaces. "I wanted more data points on my light curves for a lot more stars than I could do myself," said Hall. "For almost twenty years amateurs had given me a way to observe stars that otherwise wouldn't have gotten observed. Once I found out there were people either with photometers or with the capability of getting photometers, it just seemed natural. It was good for science and satisfying for the amateurs to do science."

Russell Genet was one of Doug Hall's amateurs. With an engineering background and an abundance of curiosity, Russ stumbled into astronomy almost by accident. "I got to wondering if I could do any science from my backyard after I helped my son do a science project," says Genet. So he went through the previous five years of the *Astronomical Journal* looking at every paper and asking himself, "Could I have done that from my backyard?" He found thirty papers he thought he could have done; twenty of them involved photoelectric photometry.. Before long he had a telescope and was doing photometry from his backyard in Fairborn, Ohio.

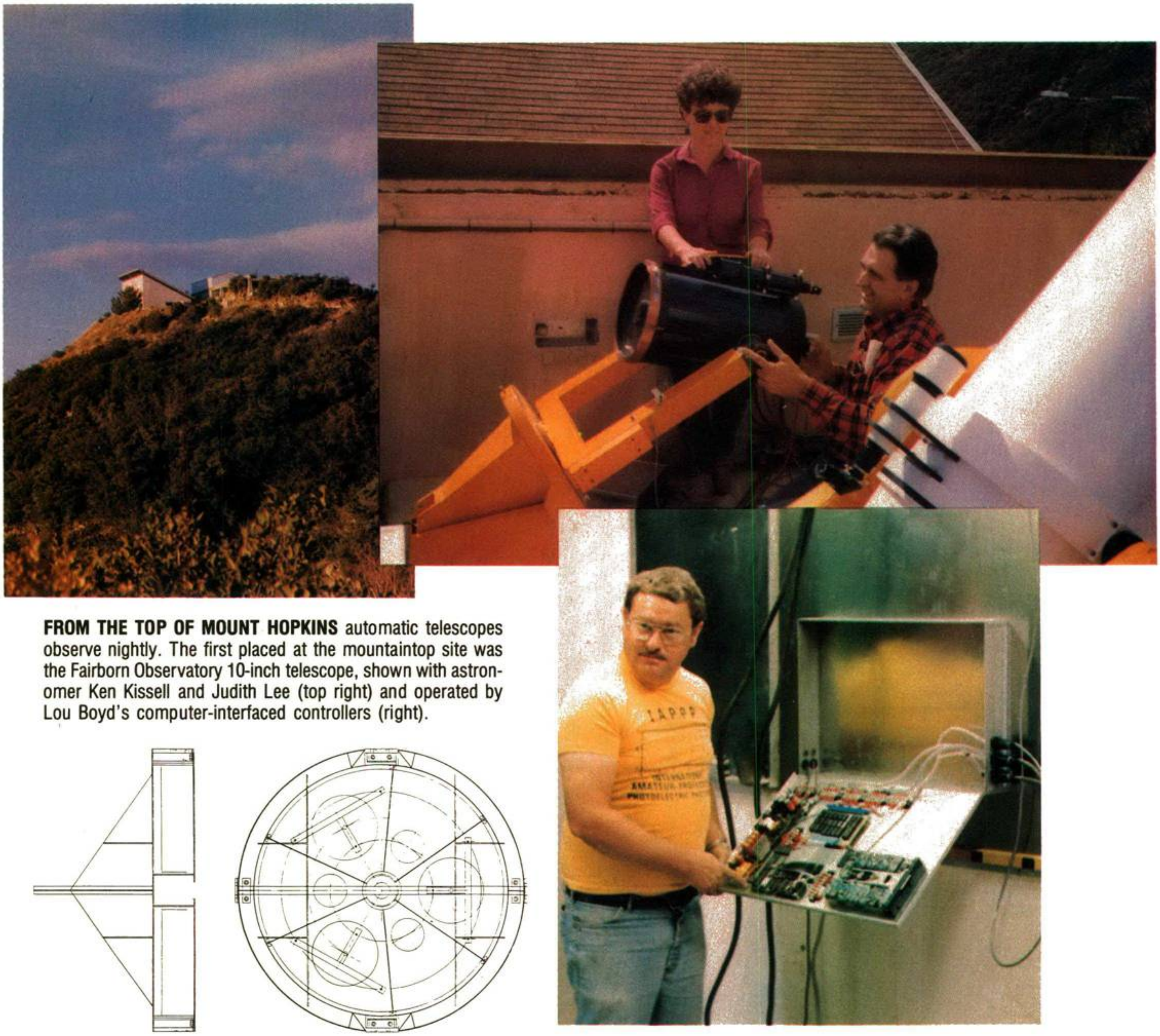
"At about that time the first Radio Shack TRS-80s were coming out," remembers Genet. "I decided I'd need a computer to do data reduction." So he plunked down his money and wrote a program to convert the raw readings from the photometer into stellar magnitudes. "It was an early model, cassette-loaded, really terrible, but when I got it going, I decided, 'Well, I'll try logging data with it.'"

It was the first step toward automation — having the computer record light readings directly. It worked so well Genet decided the computer ought to be pointing his telescope as well.

"It was about that time I met Lou Boyd. He'd already reached the same conclusion and was building a 10-inch fully automatic telescope. That was May 1981." An engineer living in Phoenix, Boyd welcomed the challenge of building a completely hands-off telescope. His computer would calculate where a star should be and then tell motors on the mounting how far to turn the telescope. To compensate for minor pointing errors, the computer would search for a star by spiraling outward from the computed position. In October 1983 Lou Boyd's automated telescope began collecting photometric data.

Boyd's telescope was an ungainly 10-inch Newtonian reflector with a square tube made out of aluminum. Digitally controlled stepping motors turned large metal disks that made up the right ascension and declination axes of the equatorial mounting. The telescope didn't even have an eyepiece — just a photometer.

"Because Lou needed some stars to test out the telescope," said Genet, "Doug became the first automatic telescope user. Lou put a list of stars from Doug on the telescope. I knew Doug would be real interested, so I took the first few weeks of measurements to an IAPPP meeting Doug was hosting at Vanderbilt and handed him the data. Well, his eyes just lit up. He recognized immediately that this could be a great source of scientific input for him. He came up with a big list of stars, about eighty of them, and we put 'em all on the telescope."



FROM THE TOP OF MOUNT HOPKINS automatic telescopes observe nightly. The first placed at the mountaintop site was the Fairborn Observatory 10-inch telescope, shown with astronomer Ken Kissell and Judith Lee (top right) and operated by Lou Boyd's computer-interfaced controllers (right).

Ten months after Boyd's telescope began operation, Genet's 10-inch — a modified Meade Schmidt-Cassegrain — came on-line in Ohio. With two APTs going full blast, Hall was soon swimming in data. "It was really fun to watch Doug," says Genet. "He was putting on lots of stars that he thought might be variables, but he didn't know yet which were and which weren't. We'd have the computer plot up the data for him, and he'd go through the curves: 'Ah, another dud, another dud,' and then 'Oh, look at this one!' And we'd see the curve going up and down, and he'd interpret the curve for us. Lou would really get turned on watching a scientist in action with data from the automatic telescope."

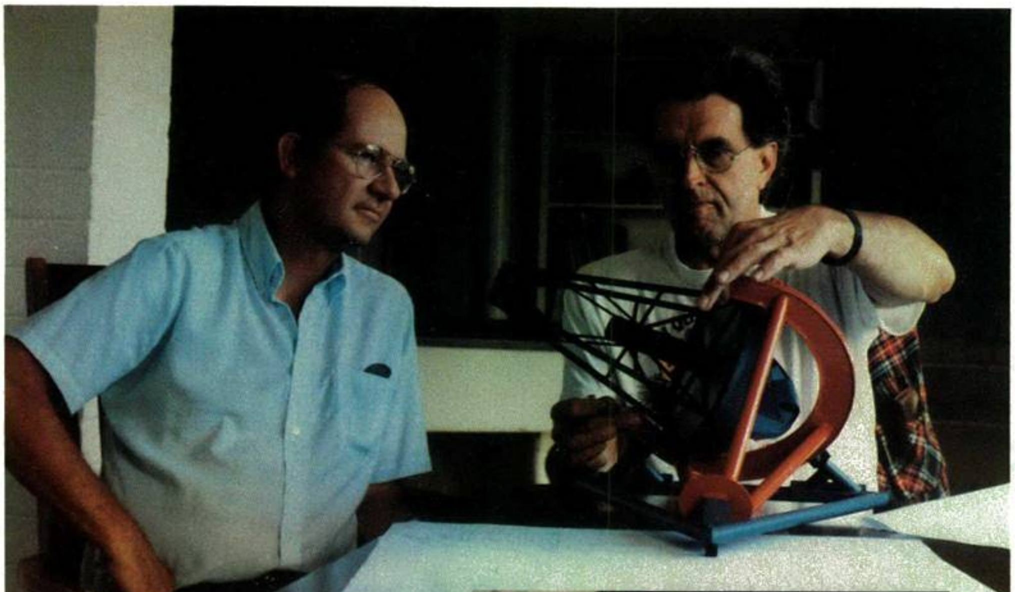
Meanwhile, Hall and Genet started looking for ways to make more and better APTs. In 1985, with a grant from the National Science Foundation, Hall began work on a 16-inch APT. Then, as word got around quickly that the APTs were producing, other professional astronomers expressed interest in supplying lists of stars. To operate the telescopes for Hall and a growing list of other astronomers, Genet and Boyd established the APT Service and started looking for a first-class mountaintop site for the telescopes. In September 1985 the APT Service and the Smithsonian Institution set up a cooperative APT observatory on Mount Hopkins in southern Arizona.

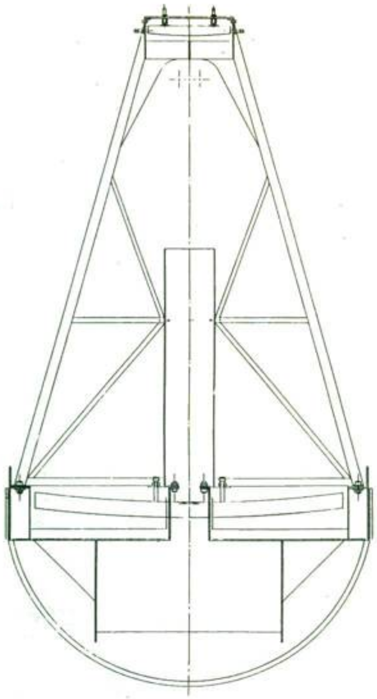
"After we made the arrangement with the Smithsonian," said Genet, "the first telescope we put on Mount Hopkins was the 10-inch telescope I'd gotten running in Ohio. We devoted it to making observations for the Smithsonian, primarily for Sallie Baliunas." The first observations were made in January 1986. By July three APTs were operating on the mountain: Genet's 10-inch, Boyd's 10-inch, and Vanderbilt University's 16-inch.

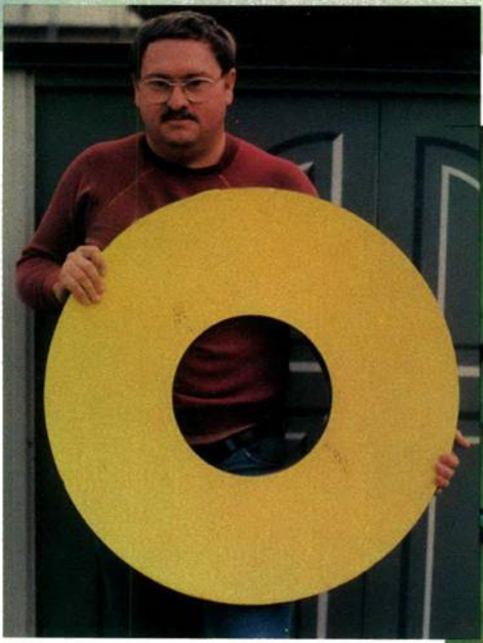
Meanwhile, Genet formed a small company, Autoscope, to build APTs. Various universities can buy complete APTs, parts for APTs, or plans and software for APTs.

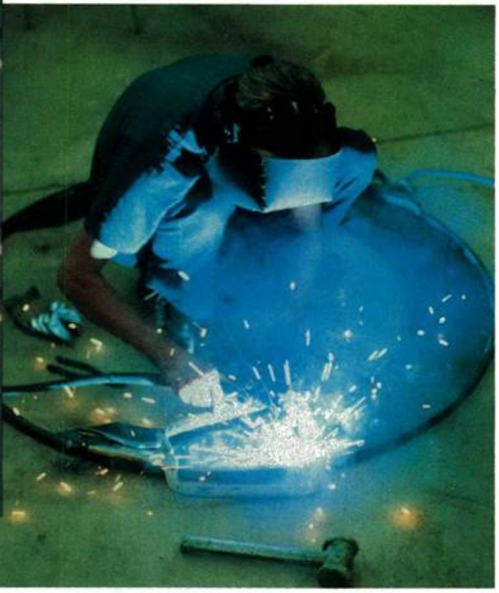
"We're planning to put four 30-inch telescopes in the south end of the building," said Genet. Housed in two spare buildings that formerly housed the Smithsonian's satellite-tracking cameras, the APT Service uses the roll-off roof observatory building for the telescopes and a warm room in the second building for the computers and electronics.

"The first 30-incher is the Smithsonian's. It's going to do calcium K-line









A NEW GENERATION of telescopes takes shape under the guidance of Russ Genet (above left), Ken Kissell (above right) and Lou Boyd with "doughnut" showing the 30-inch aperture of the new telescopes. Telescope construction is deliberately simplified so third-world countries can benefit from the new technology. Mike Genet welds the polar disk of the first 30-inch new generation small telescope (far right).

photometry on solar-type stars — just like the 60-inch telescope at Mount Wilson — and because of the complementary weather patterns, they'll get almost continuous coverage of their stars."

The second 30-inch belongs to a four-college consortium of the College of Charleston, The Citadel, Villanova, and the University of Nevada at Las Vegas. "The problem," says Genet, "is how to schedule all this stuff together on one automatic telescope."

The Automatic Telescope Instruction Set, or ATIS, will solve the scheduling dilemma. "We're setting it up so you can just sit down at your Mac or your PC and make up an observing request," said Genet. When it comes time to observe, the telescope itself — with considerable intelligence — schedules what it's going to observe.

The third 30-inch belongs to Fairborn Observatory, the observatory Genet and Boyd founded when they first began serious observations. Fairborn will lease half the telescope's time to another user and retain the rest for its "Rent-a-Star" program. Genet explains, "The idea is that some institutions don't want very much telescope time, they just want to make a few observations. We'll do that for them with Rent-a-Star."

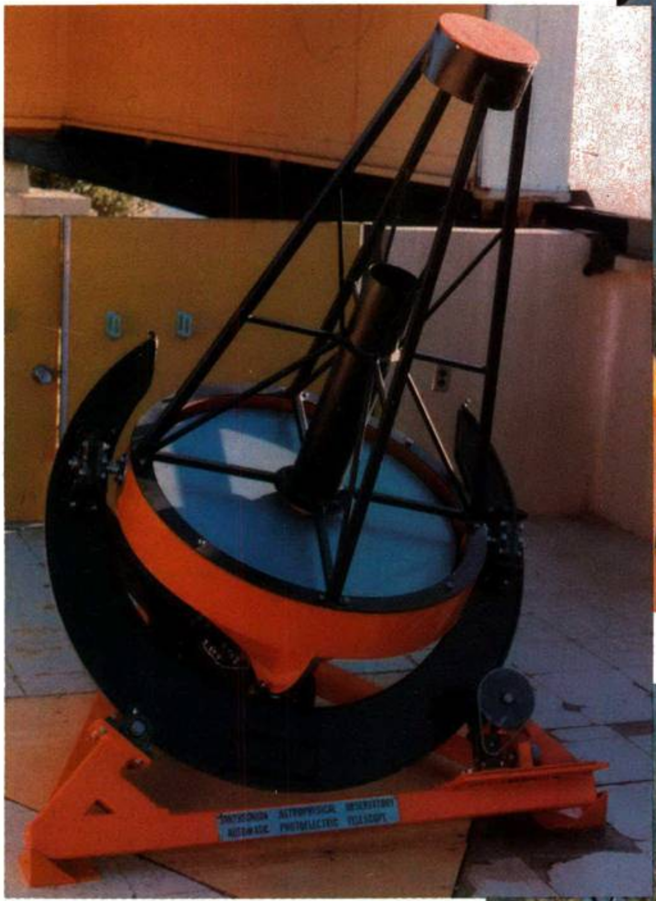
"The fourth 30-inch is up for grabs," said Genet. "We hope another consortium will sign up for it."

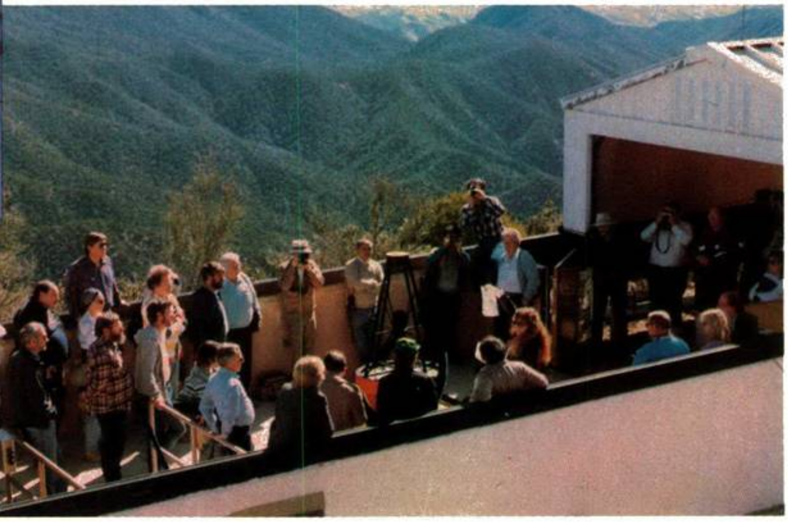
Low-Cost, High-Quality Science

Genet's new 30-inch telescopes will do much more than the original APTs — so much more that David Crawford coined a new name for them: New Generation Small Telescopes, or NGSTs for short. "The APT was a step on the way," declares Crawford, "but there are limitations in the software. When one speaks of the new generation of automatic telescopes, it's really a new generation of software."

The NGST software is far more flexible than the original APT software. Built around phone-in observing requests, the software will schedule many different observing programs. What's even more remarkable is that existing APTs will become NGSTs just by changing to the new software.

The impact of NGSTs on the science of astronomy is just beginning to be felt as astronomers learn to exploit the capabilities NGSTs offer. More than twenty observatories — the number is growing — now contract to have photometry done by the APT Service. These astronomers come from all over the United States and also from Ireland





DEDICATED TO PHOTOMETRY, the Smithsonian Institution's new automatic telescope (above) will soon begin a decades-long task of measuring activity of solar-type stars. Shown at its dedication (right) in February 1988 is the Smithsonian's 30-inch telescope. Assembling the telescope (top right), Russ and Mike Genet wrestle the mirror cell onto the mounting.

and the Netherlands.

Astronomers are delighted with automated telescopes. "I couldn't have attempted a comprehensive observing program," said telescope user Baliunas, "because I would have had to spend my whole time at the telescope. I wouldn't have gotten around to doing any science. Now I can choose my program stars, sleep in the night, and then wake up in the morning and have fresh data."

The scientific funding institutions are also watching NGSTs. Do they produce good science? "We'd like to see a lot of publications come out," says Frank Giovane, program director for instrumentation and development in the division of astronomy of the National Science Foundation, "because that of course will identify their usefulness. If the papers they produce can get into the journals, make a contribution to the science, then they're of value. If they're simply an exercise in automation, then they're not of value."

Monitoring Spotted Stars

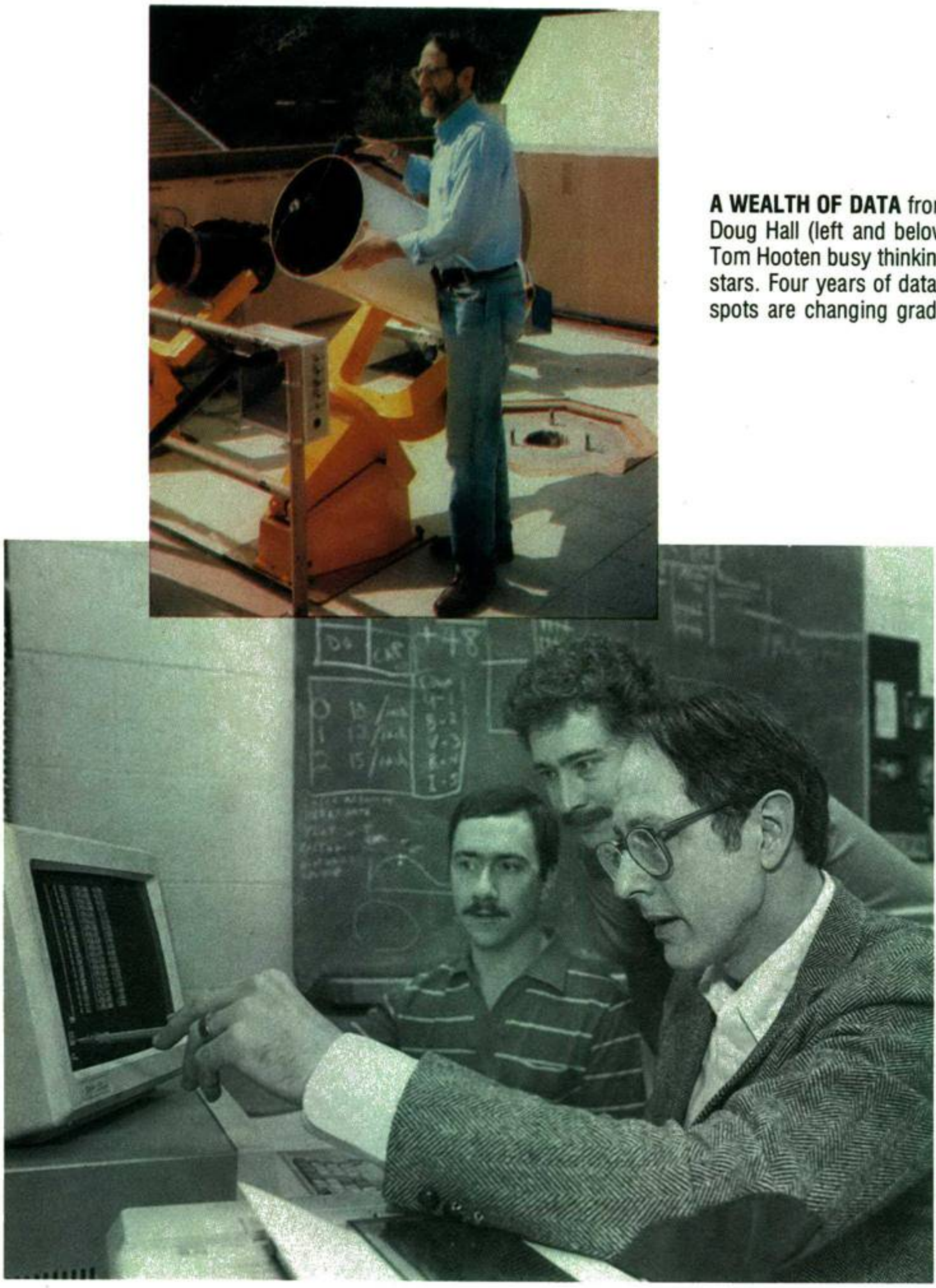
Doug Hall studies RS Canum Venaticorum stars — heavily spotted stars that Hall hopes one day will yield insights into stellar structure. To do that, he needs data. He needs to know how fast and by how much a star's light varies, and he needs to monitor the star's variation year after year to determine whether and by how much the number and size of the starspots can change.

Hall's first goal is to determine whether an interesting star is a variable. To do that, he places candidate stars on the APT observing schedule. "Even after just one season you know the period of the variation. That period will be the rotation period of the spotted star."

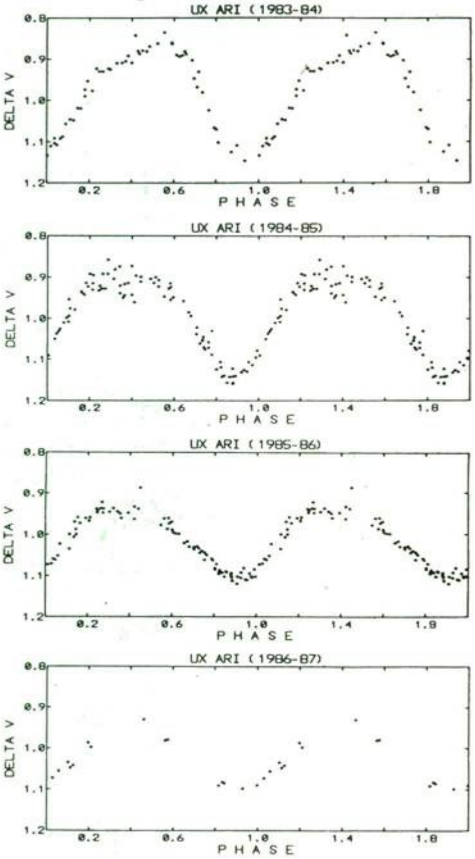
Understanding the structure of stars — and ultimately our own star the Sun — involves the study of convection and magnetic fields. Both starspots and sunspots are intimately related to the convective layers. "The bottom line is this," explained Hall, "if a star has convection in its outer layers, it will have spots. And if it's rotating fast, it will have *lots* of spots.

"Every one of the things we see on spotted stars is something the Sun is doing also," said Hall. "It's just a matter of degree. The stars are just doing it more."

Sallie Baliunas also studies spotted stars. "What we're doing is related to what Doug Hall is doing, but it's different. He's looking at big spots on RS



A WEALTH OF DATA from the Vanderbilt 16-inch APT keeps astronomer Doug Hall (left and below, right) and graduate students Tim Ferris and Tom Hooten busy thinking about heavily spotted RS Canum Venaticorum stars. Four years of data (below) show that the variable star UX Arietis' spots are changing gradually.



Canum Venaticorum stars; we're looking at activity on solarlike stars."

Baliunas monitors stellar activity — starspot activity — using the 60-inch telescope on Mount Wilson with a special photometer that measures the strength of the ionized calcium line. She's looking for evidence of cycles — like the Sun's sunspot cycle — on other Sunlike stars.

"We're now looking at a hundred other stars like the Sun — old stars — and we see a correlation in their light too. When there are more spots, old Sunlike stars are brighter." This ties directly to our own star's activity.

"Something very interesting recently came out of the *Solar Max* satellite," explained Baliunas. "The Sun's radiance — the total amount of energy it puts out — changes during the solar cycle. An old star like the Sun gets brighter when there are more sunspots, and it gets fainter when there are less sunspots.

But the opposite is true for the *young* Sunlike stars Baliunas studies. "The 1 billion-year-old Sun was quite different than it is today," says Baliunas. "We're learning how the young Sun varied, and that its variation was much more dramatic than it is today. That much variation had to have had a huge impact on the atmosphere of the early Earth."

Revolution in the Making

"NGSTs offer a good ratio of science per dollar," said Crawford. "These telescopes are absolute dynamite because the cost is low and the science is high." A bare-bones 30-inch NGST costs about $100,000 — one third to one tenth the cost of a conventional 30-inch telescope. Split three or four ways, even small colleges can afford part of an NGST.

"My intent is to spread the technology," said Genet, "to make it available to more people. With Autoscope, we're putting together a manual that gives all the details on how to build an NGST. We designed them so people in third-world countries could build them. Of course there'll be some places that don't want to go to the hassle of building a telescope, but we'll do that for them."

"You realize," says Crawford, "you can fund, build, and put into operation one of these NGSTs quicker than you can have the meetings to discuss building one of the big telescopes. I think the small ones working at the cutting edge of automation will give guidance to the big ones and make the big ones even more effective." ☐

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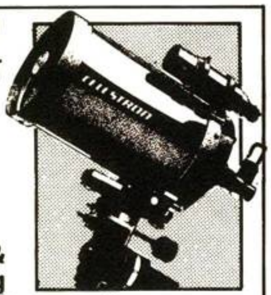

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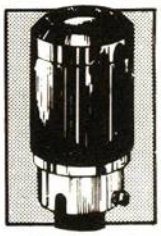

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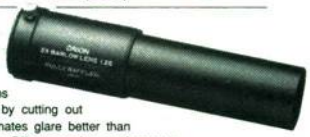
Kellner $22.95 (1.68)
6mm (#8450), 9mm (#8452), 12mm (#8454), 18mm (#8456), 25mm (#8458)

Wide Angle AH $22.95 (1.68)
Ideal for smaller refractors which do not come with a low power eyepiece. 40mm (#8460)

Orion Deluxe Fully-Baffled 2x Barlow Lens



This fine 1.25" barlow lens produces higher contrast by cutting out stray off-axis light. Eliminates glare better than other competing models. Offers premium performance at a remarkable price.

#8746 **$49.95** (1.68)

Orion Fully-Coated 2x Barlow Lenses

Fine mechanical and optical design, superior to most standard barlow lenses. Ideal for compound telescopes and reflectors. Provides all the advantages of the useful 2x barlow design at an affordable price.

1.25" #8744 **$37.95** (1.68)
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Excellent quality wide-field eyepieces.

Orion 50mm Plössl, 2"
Offers the brightest, widest field. Preferred for extremely faint celestial phenomena.
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Aluminum adapters allow you to use different size eyepieces with your telescope.

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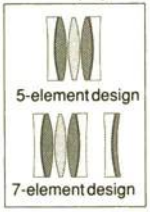
New! Orion Ultrascopic™ 1.25" Eyepieces


5-element design

7-element design

Our new Orion Ultrascopic eyepieces are 5 to 7 element designs using modern high refractive index glasses and modern manufacturing methods. They provide a wide, flat field, excellent contrast, and freedom from false color. Every eyepiece utilizes multi-layer optical coatings to provide the highest possible transmission and freedom from stray reflection. Each of the 6 to 8 air-to-glass surfaces is anti-reflection coated. Each eyepiece is parfocal so you won't need to refocus when switching eyepieces within the series, except for the 35mm which was optimized for the widest field possible in a 1.25" barrel.

Wide Field 5-Element

35mm (#8560) **$99** (2.19)
30mm (#8562) **$89** (2.19)
25mm (#8564) **$79** (1.88)

For incredible deep sky observing, they provide a wide 52° apparent field of view (49° on the 35mm), using a well corrected 5-element Plössl-type symmetrical design. Ideal for observing the larger nebulaes, star clusters, and galaxies such as the Andromeda Galaxy, the Beehive Star Cluster, and the Orion nebula. Pinpoint, high contrast images to the very edge. Compare these fine oculars to other brands selling for much more; you'll be impressed.

Medium-High Power 5-Element $69 (1.88)

Our highly corrected 5-element design provides a 52° apparent field and excellent eye relief. The 10mm and 7.5mm models are particularly desirable for high power planetary and lunar observation, as well as for observation of the smaller planetary nebulas and star clusters. The 15mm model is ideal for moderately high power views of both deep space and planetary subjects. The 20mm is excellent for medium power views of intermediate sized nebulas and larger globular clusters. Superb contrast and brightness with pinpoint images right to the edge. Multi-coated, parfocal, and threaded for filters. Try them under our 100% satisfaction guarantee and save!

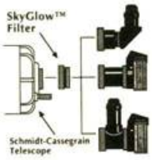
20mm (#8566), 15mm (#8568), 10mm (#8570), 7.5mm (#8572)

High Power 7-Element 1.25" $89 (1.88)

For high power applications such as planetary and double star observation, these impressive eyepieces provide unprecidented eye relief and width of field in a high power design. Consisting of 5-element ocular and an integral 2-element barlow lens, they provide excellent freedom from glare and stray reflection due to the multi-coated construction. The 52° field is wider than most other designs. Blackened lens edges and first-rate multi-coatings provide the high contrast for demanding planetary observation. May be used with any barlow lens for even higher power.

5.0mm (#8574), 3.8mm (#8576)

Orion SkyGlow™ Enhanced Light Pollution Filter



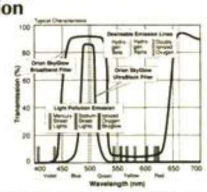
City bound astronomers, enhance your viewing of faint deep sky objects with the best broadband light pollution filter you can buy. Our SkyGlow filter absorbs the frequencies emitted by city lights, allowing transmission of the rest of the visible spectrum. You'll see dramatic results. Ideal for visual observation, and photography. Try one, you'll be amazed!

1.25" Eyepiece SkyGlow #5660 **$79** (1.68)

Rear Cell SkyGlow for Meade or Celestron 4", 8", 10" Schmidt-Cassegrains. #5658 **$109** (2.19)

New UltraBlock™! The SkyGlow™ Filter for Severe Light Pollution

SkyGlow Filter



The combination of high transmission of desireable bands and extremely low transmission of pollution bands results in the highest contrast gain of any competing light pollution filter you can buy. Blocks out 99.9% of critical mercury and sodium emissions. Better blocking than any competing filter at any price. Brings out high contrast of planets and nebulas.

1.25" Eyepiece Ultra Block #5654 **$99** (1.68)

Rear Cell UltraBlock for Meade or Celestron 4", 8", 10" Schmidt-Cassegrains. #5656 **$139** (2.19)

Orion Moon Filters $14.95 (.99)

Cuts 87% of the light from the Moon.

1.25" (#5662) **.965"** (#5664)

Variable Polarizing Filter $29.95 (1.68)

Adjustably reduces light transmission for more detail on bright objects. **.965"** (#5558), **1.25"** (#5560)

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Set of 4 Color Primary Filters
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Deluxe set of 8 Color Filters
Includes all filters in Primary and Auxillary Sets. #20278 **$76** (1.88)

Individual filters sold separately.

High Power Illuminated Reticle Eyepiece With Adjustable Reticle Positioning

New high power 6mm Orthoscopic illuminated reticle eyepiece has unique reticle design, useful for astrophoto guiding as well as for measurement and population studies. Two spring-loaded micro-adjusters smoothly adjust the reticle with a light touch. Wireless illuminator uses a low power LED that will never burn out. Variable brightness control. Uses two standard SR-44 batteries, not included.

#8487 **$139** (2.09)

Bull's-eye Illuminated Reticle Eyepiece With Adjustable Brightness

9mm Orthoscopic eyepiece with wireless adjustable brightness illuminator. Bull's-eye within three concentric circles helps measure limits of acceptable guiding error.

#8488 **$119** (1.88)

Illuminated Reticle Eyepiece For Telescope Power Panels

12mm Kellner eyepiece with cable plugs into LX/3 and LX/5 drive bases, and most drive correctors with illuminated reticle output for polar alignment and guiding.

#8482 **$79** (1.68)

Orion Universal Camera Adapter

Combination Eyepiece Projection Tube and Prime Focus Adapter for refractors and reflectors. Use with T-Ring to match your 35mm camera.

1.25" Model #5264 **$34.95** (1.68)

.965" Model #5268 **$34.95** (1.68)

Orion T-Adapter

For prime focus photography. Use with T-ring to match your 35mm camera. For Meade, Celestron 8", 10" SC.

#5116 **$27.95** (1.68)

Orion Tele-Extender

For high powered photography with Meade, Celestron 8", 10" Schmidt-Cassegrain.

#5125 **$27.95** (1.68)

Orion Image Erecting (Porro) Prisms

Look straight through the telescope, without a right-angle diagonal prism.

Erecting Prism .965" #8756 **$39** (1.68)

Erecting Prism 1.25" #8757 **$44** (1.68)

Orion Off-Axis Guider Body For Precision Astrophotography

Use with any 1.25" Illuminated reticle eyepiece. For Meade, Celestron 8",10" Schmidt-Cassegrain.

#5144 **$68.95** (1.88)

Off-Axis Guiding System with 12mm Kellner eyepiece, #8482 (listed separately). #20272 **$129** (1.88)

Off-Axis Guiding System with 9mm Ortho eyepiece, #8488 (listed separately). #20274 **$169** (1.88)

Off-Axis Guiding System with 6mm Ortho eyepiece, #8487 (listed separately). #20276 **$189** (1.88)

Wireless Illuminator

Replace the battery pack and cable on your Orion, Meade, or other thread-on externally-powered illuminated reticle eyepiece with this wireless illuminator. Adjustable brightness knob. Uses two SR-44 batteries, not included.

#8480 **$37.95** (1.68)

Tele Compressor Lens with Multi-Coatings

Get four times the brightness and 1/2 the exposure time. Double your field of view for astrophotography. For Meade, Celestron 8", 10" SC.

#5141 **$34.95** (1.68)

Extension Tube
Needed when using Tele Compressor with Off-Axis Guider.
#5123 **$19.95** (1.68)

Orion Rich Field Adapter with Multi-Coatings

Adds 4x the image brightness and twice the field of view. For Meade, Celestron 8", 10" SC.

#5128 **$99** (2.19)

45° Correcting Diagonal

Correct images and convenient 45° angle viewing. Perfect for terrestrial use. Eliminates the need to crouch behind scope. For 1.25" eyepieces.

#8765 **$69** (1.88)

Rubber Eyeguard

Cuts ambient light. Enhances viewing comfort. Fits most 1.25" eyepieces.

#7405 **$3.95** (.65)
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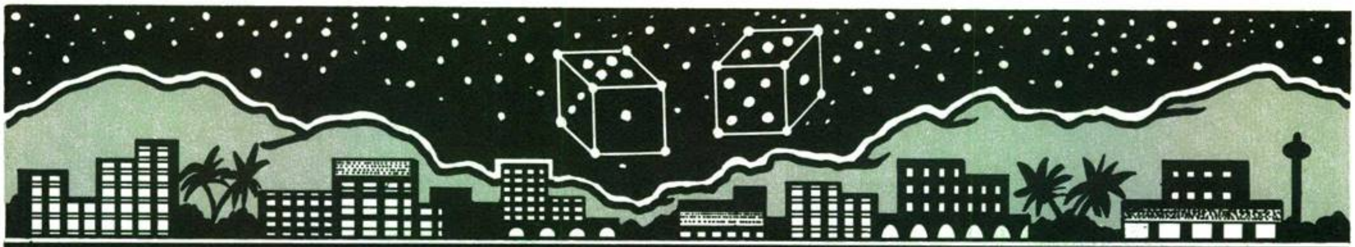

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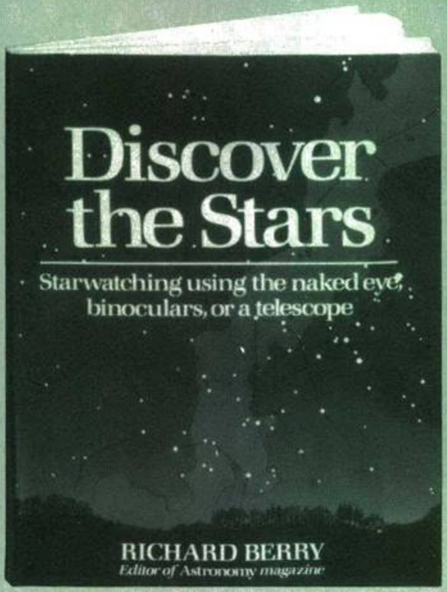
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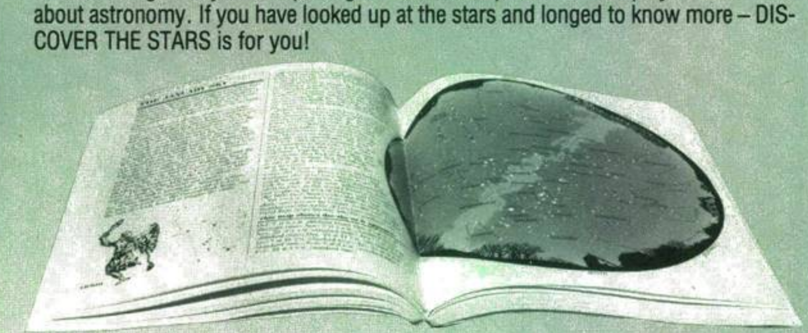

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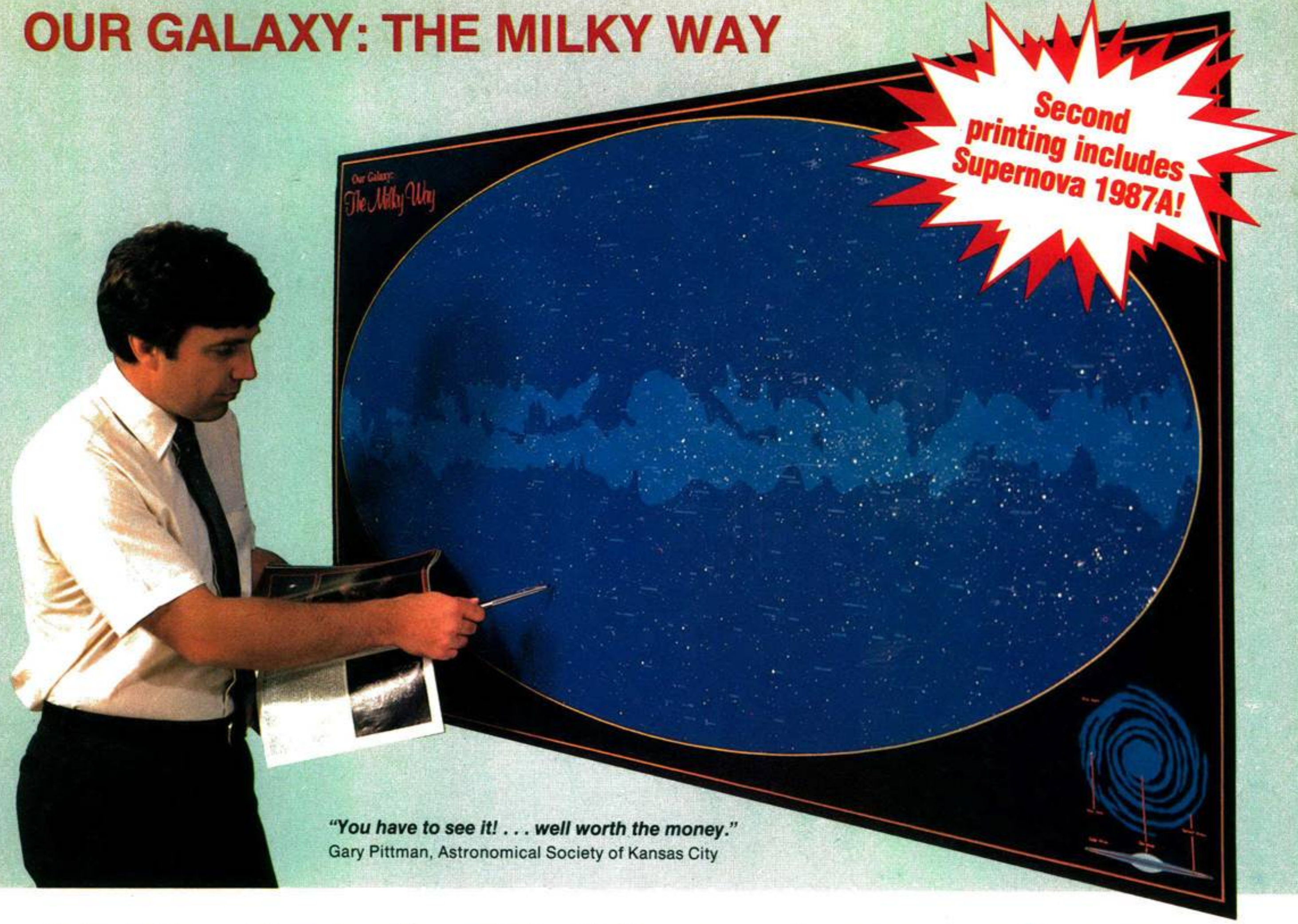
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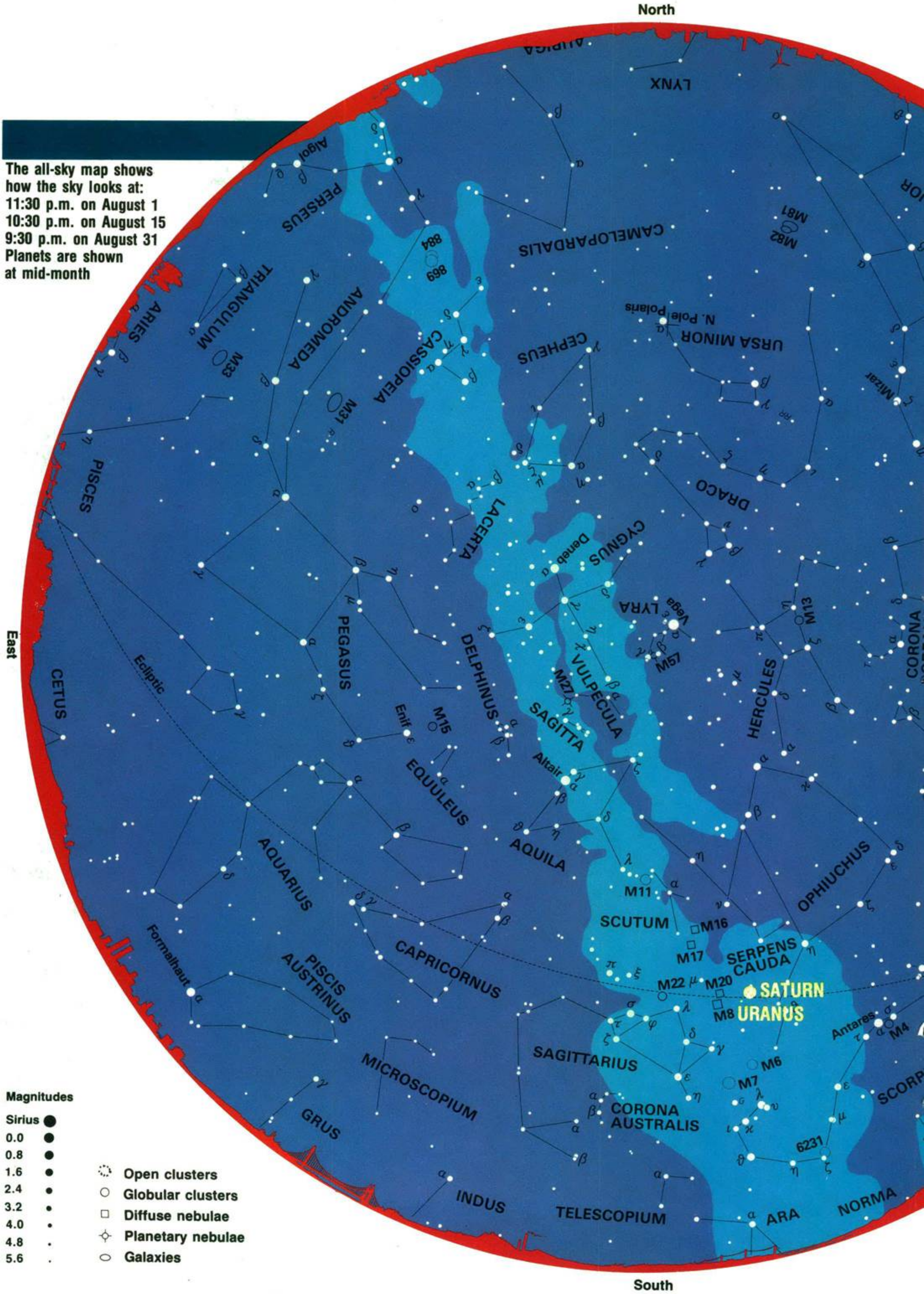
2944
NGC-3114
IC 2602
CARINA
NGC-2516
ON

Carina section of OUR GALAXY

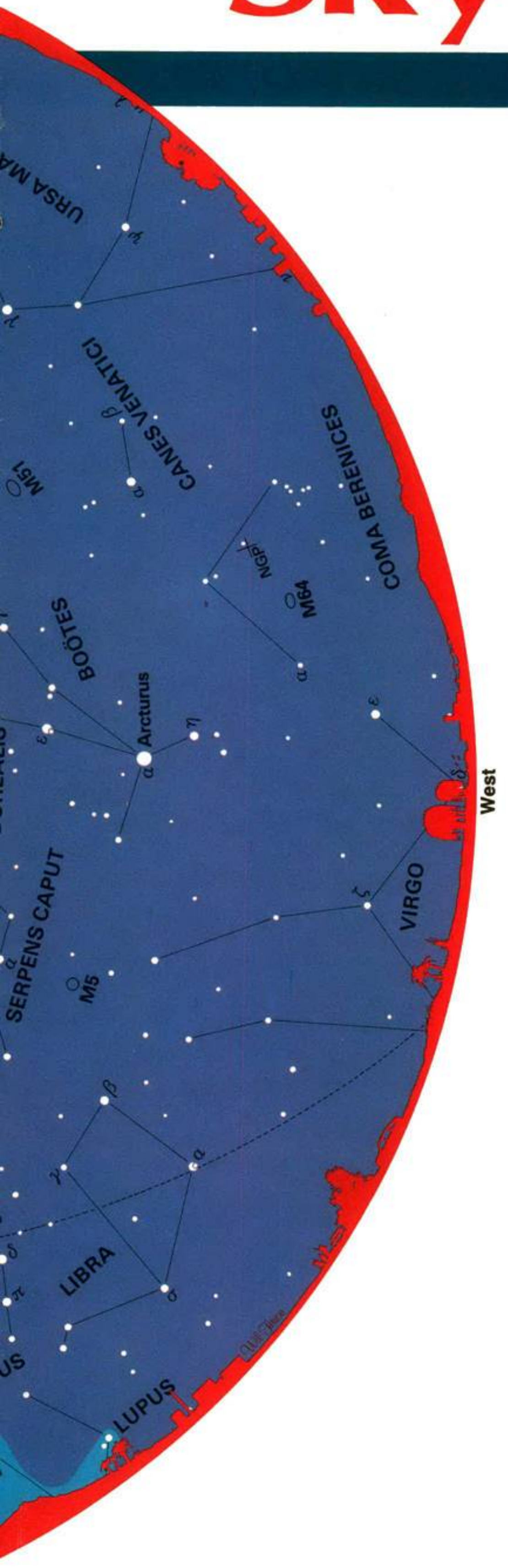
Stars shown to actual size

The all-sky map shows how the sky looks at:
11:30 p.m. on August 1
10:30 p.m. on August 15
9:30 p.m. on August 31
Planets are shown at mid-month


North
South
East
AURIGA
LYNX
PERSEUS
Algol
CAMELOPARDALIS
M81
M82
884
869
TRIANGULUM
ARIES
ANDROMEDA
CASSIOPEIA
N. Pole Polaris
URSA MINOR
CEPHEUS
M33
M31
Mizar
PISCES
DRACO
LACERTA
CYGNUS
Deneb
LYRA
Vega
M13
CORONA
PEGASUS
DELPHINUS
VULPECULA
M57
M27
HERCULES
CETUS
Ecliptic
Enif
M15
SAGITTA
Altair
EQUULEUS
AQUILA
AQUARIUS
OPHIUCHUS
M11
SCUTUM
M16
M17
SERPENS CAUDA
Formalhaut
CAPRICORNUS
PISCIS AUSTRINUS
M22
M20
M8
SATURN
URANUS
Antares
M4
SAGITTARIUS
M6
M7
SCORP
MICROSCOPIUM
GRUS
CORONA AUSTRALIS
6231
INDUS
TELESCOPIUM
ARA
NORMA
Magnitudes
Sirius ●
0.0 ●
0.8 ●
1.6 ●
2.4 •
3.2 •
4.0 •
4.8 ·
5.6 ·
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies

Sky Almanac

AUGUST 1988



Map Art by Wil Tirion

PERSEIDS PEAK ON AUGUST 12

The best warm-weather meteor display is the Perseid shower, and this year it occurs with the Moon out of the sky. As a result, you can expect to see fifty or more meteors each hour on the morning of August 12 and perhaps half that number for a day or two before and after.

MARS GROWS STEADILY BRIGHTER

For naked-eye viewers the Red Planet doubles in brightness and is conspicuous from the time it rises in late evening until dawn. For telescopic viewers Mars' disk grows nearly 30 percent larger this month and is big enough to show considerable surface detail.

MOON ECLIPSED ON AUGUST 27

The Full Moon passes through the southern edge of Earth's umbral shadow in the early morning hours of August 27. Observers from central and western North America westward to Australia and eastern Asia will see 30 percent of the Moon covered at maximum eclipse.

VENUS AT BEST VISIBILITY

Venus rises over three hours before the Sun in August and is high in the eastern sky as dawn approaches. Venus passes through greatest elongation on August 22, so observers with telescopes can watch it change from a crescent to a gibbous phase during the month.

Dates and Times

2 Pallas at opposition
3 Mercury in superior conjunction
4 Last Quarter Moon, 2:22 p.m. EDT
12 New Moon, 8:31 a.m. EDT
Mars at perihelion
Perseid meteor shower peaks in morning
14 Moon at apogee (252,475 miles from Earth)
20 First Quarter Moon, 11:51 a.m. EDT
21 The Moon passes 0.7° south of Antares, 10:30 a.m. EDT
22 Venus at greatest western elongation (46°)
26 Mars stationary
27 Full Moon, 6:56 a.m. EDT, and partial lunar eclipse
Moon at perigee (221,892 miles from Earth)
30 Saturn stationary

Eye on the Sky by Deborah Byrd

A GREAT YEAR FOR THE PERSEIDS

The Perseid meteor shower is at its best this year on the morning of August 12, but will be good a few days before and after that date. The Moon is New on August 12, so this should be a grand year for observing the Perseids. It's best to watch after midnight, when your part of Earth is turned into the meteor stream. Leave your telescope at home and stretch out on a lawn chair or blanket beneath a dark country sky. You might see around fifty Perseid meteors per hour, probably in bursts of two or three every few minutes. (See "Dark Skies for the Perseid Meteor Shower" by Philip M. Bagnall on page 78.)

Ten years ago the Perseid shower was the undisputed king of meteor showers. Now, many people believe the cold-weather Geminids of December are superior. With the Moon out of the way for the Perseids and setting before midnight for the Geminids later this year, you can make hourly counts for both showers and compare them.

The Perseids are named for the constellation Perseus, which ascends in the northeast during the wee hours. The paths of the meteors, if traced backward in the sky, appear to radiate from near the northern edge of Perseus. Still, you don't need to face northeast. The meteors often appear at some distance from their "radiant point." In other words, you can find them unexpectedly in any part of the sky. This element of surprise is part of the fun of watching meteors.

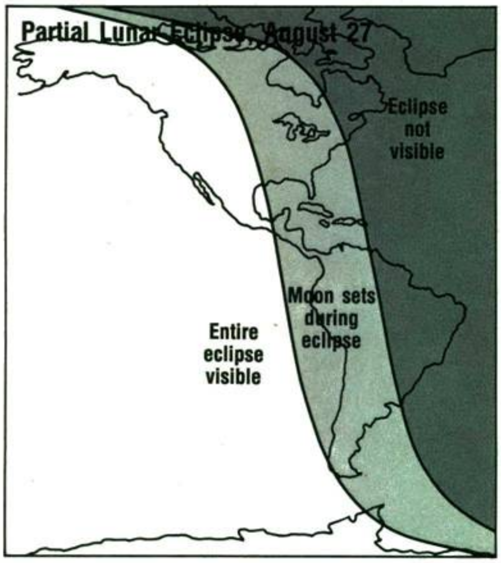
UNMISTAKABLE MARS

The Red Planet is impossible to miss this month. Rising in mid-evening, Mars is extremely bright with a color like a candle flame — a brilliant beacon in the night sky. People who casually glance up will wonder, "What IS that red star?"

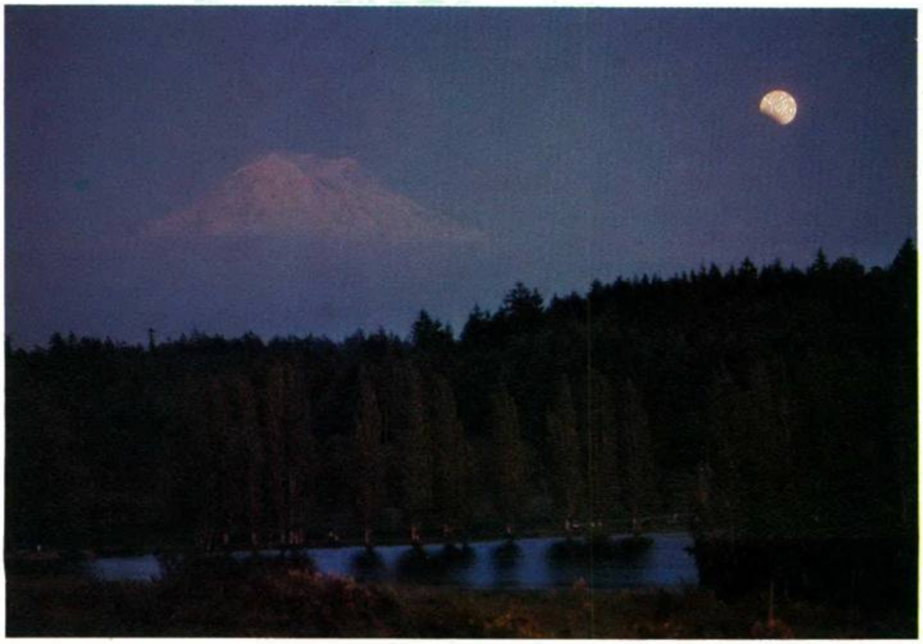
Mars doubles in brightness during August, climbing from magnitude −1.5 in early August to −2.3 at month's end. In early September Mars will shine as bright as mighty Jupiter, and for the remainder of the month it will be even brighter than Jupiter. When Earth passes between Mars and the Sun in September, the Red Planet will be closer and brighter than at any time since 1971. Mars remains bright for only a few months, however, so you should begin watching it now.

THE MOON SLIDES INTO EARTH'S SHADOW

In the early morning hours on August 27, the Full Moon undergoes a partial eclipse visible from North America, except for observers on the East Coast. Those west of a line from Winnipeg, Manitoba, to Houston, Texas, can see the entire umbral eclipse, when the dark central part of Earth's shadow inches across the face of the Moon. Slightly less than a third of the Moon appears dark at mid-eclipse, which occurs at 4:05 a.m. PDT. The Moon is at perigee, its closest approach to Earth on this orbit, later the same day.



WATCH THE MOON DIM on the morning of August 27 from central and western North America (above). At maximum eclipse the Moon will appear 30 percent obscured (below).



VENUS APPEARS FARTHEST FROM THE SUN

Last month Venus ascended rapidly in the eastern sky before dawn; this month the brightest planet climbs more slowly, appearing only a little higher at the beginning of each new day. On August 22, Venus lies 46° west of the Sun, its greatest elongation for this apparition. It rises nearly four hours before the Sun does and casts a fair light from high in the east before dawn.

AUGUST'S PLANETS

At nightfall, before Mars rises, Saturn is the only prominent planet. It appears low in the southern sky in the constellation Sagittarius and shines with a soft golden color. When you look at Saturn, you are looking in the same general direction of the center of the Milky Way Galaxy. Under a dark sky this rich region of the summer Milky Way is clearly visible. More difficult to distinguish is 5.6-magnitude Uranus, located less than 2° southeast of Saturn.

Because of Saturn's retrograde (westward) motion, the planet has returned to nearly the same place with respect to the stars that it occupied at the beginning of the year. Its retrograde motion ends on August 30; for a few nights around this date the ringed planet is almost motionless against the starry background. In September Saturn will be moving noticeably eastward again.

Saturn was closest to Earth in June, and since then the planet has grown dimmer as the distance between our two worlds increases. This month Saturn fades a bit, from magnitude +0.2 to +0.4, which makes it only slightly brighter than Antares, the brightest star in this region of the sky.

Both Saturn and Antares pale in comparison to Mars, which rises around 11 p.m. daylight time early in the month and around 9 p.m. by month's end. Mars is exceptionally brilliant, without equal until Jupiter rises about two hours later.

This is an extremely favorable year to view Mars. The key to this excellent apparition lies in an event that occurs this month. On August 12, Mars reaches perihelion — the closest point to the Sun in its orbit — and lies just 128 million miles from the Sun. Next month Earth passes between the Sun and Mars. Thus, Earth will be close to Mars when Mars is closest to the Sun. It's because these two events take place only forty-seven days apart that Mars appears so bright.

Mars has moved eastward against the stellar background all year, passing through many constellations. Now Mars is located in the non-zodiacal constellation Cetus, where it will linger throughout September. On August 26, the planet begins retrograde motion. You can track its apparent change in direction by watching the position of Mars with respect to the sides of the Great Square in the constellation Pegasus.

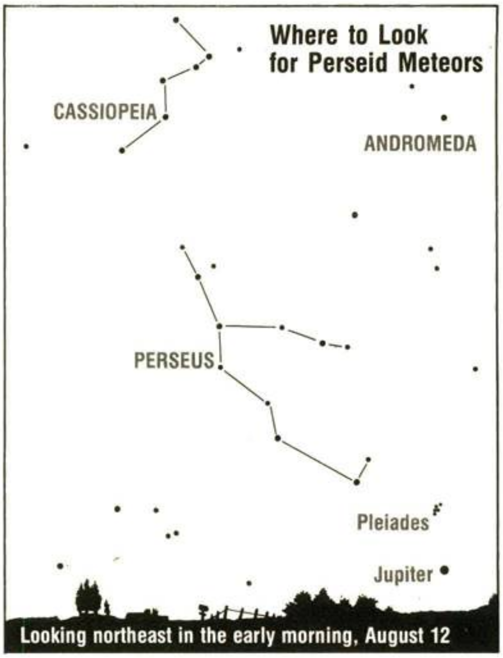
Mars is the main attraction in the evening hours, but don't let it keep you from getting up before the Sun to view the morning sky. Jupiter rises in the middle of the night in the company of what we generally consider the "winter" stars. Moving slowly eastward, Jupiter is sandwiched between two famous star clusters: the Pleiades and the Hyades. The Pleiades are shaped like a tiny dipper and appear wrapped in a misty veil. The Hyades — which represent the face of Taurus the Bull — are shaped like the letter "V".

Jupiter isn't the brightest object in the predawn sky, however. Dazzling Venus outshines all the planets and stars from its perch high in the east. Although it was at its brightest last month, Venus is only slightly fainter now and fades almost imperceptibly from magnitude −4.4 to −4.3 during the month. It is so bright and so far from the Sun that you should have no trouble seeing it in a dark blue sky shortly after sunrise.

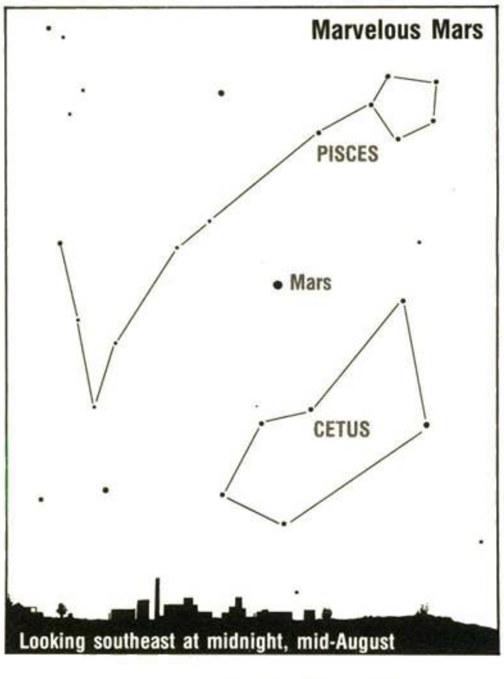
Venus moves from Taurus into Gemini this month. Next month it will appear in a line with the starry eyes of Gemini — the bright stars Castor and Pollux.

AUGUST'S STARRY SKY

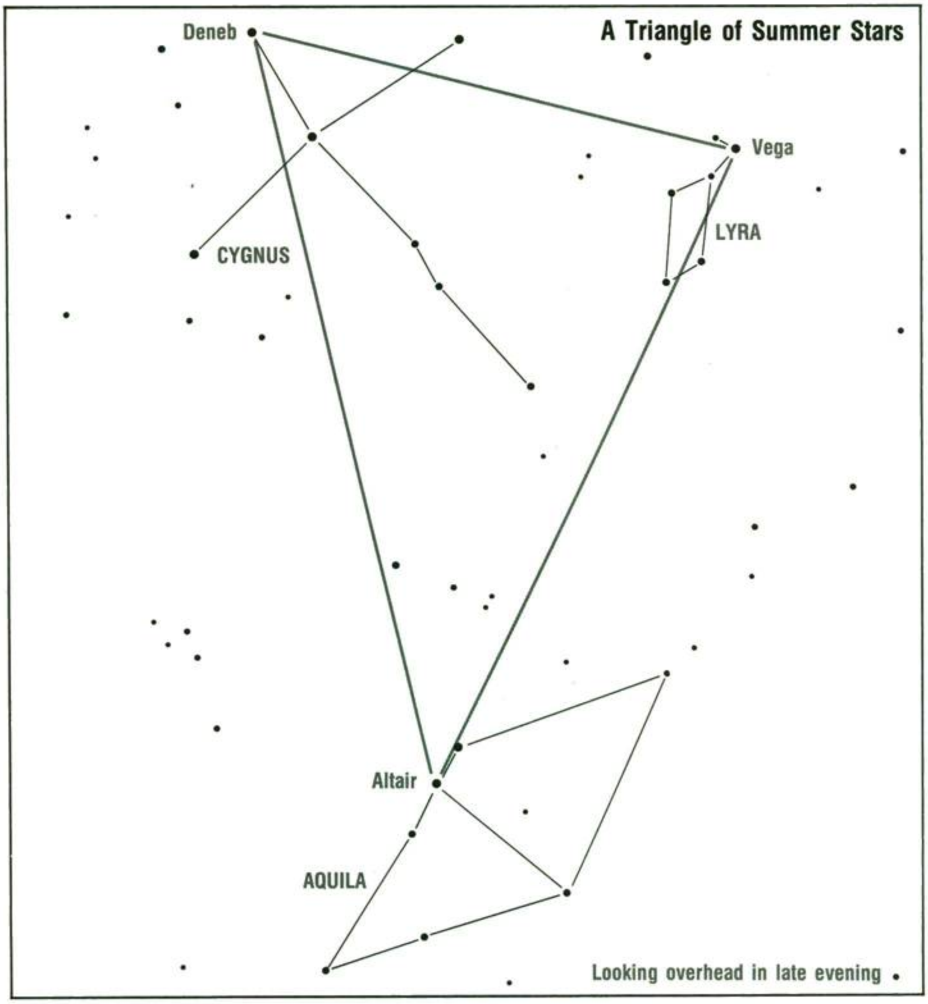
The combination of warm weather, a New Moon, and a dark observing site should give you a great view of this year's Perseid meteor shower. But the same conditions also give you a splendid opportunity to observe


Where to Look for Perseid Meteors

Looking northeast in the early morning, August 12


Marvelous Mars

Looking southeast at midnight, mid-August



A Triangle of Summer Stars

Looking overhead in late evening

the summer sky.

At around midnight, just before the Perseids kick into high gear, the two most prominent "stars" in the sky are the planets Mars and Jupiter. Ruddy Mars is high in the southeast and Jupiter is just poking above the eastern horizon; both are five times brighter than any other object in the sky.

This is the best time to find the three stars that make up the most prominent asterism in the summer sky. Nearly overhead at midnight is Cygnus the Swan with its bright star Deneb. West of Cygnus is Lyra the Lyre, which contains the bright, blue-white star Vega. And south of them both is Aquila the Eagle with its bright star Altair. Vega, Deneb, and Altair form a star pattern called the Summer Triangle.

The star Vega is the brightest star in the Summer Triangle. It's also exceptional because of its light blue color. Fourteen thousand years ago Vega was the north star, which means it was directly above the axis of Earth. Since then Earth's axis has moved — a motion called precession — and the honor is now given to Polaris. Since precession is a cycle, Vega will be the north star again in another 12,000 years.

Vega also has a more modern claim to fame. In 1983 the *Infrared Astronomical Satellite* discovered a disk of solid particles encircling the star. Astronomers think that the material in orbit around Vega might be a planetary system in the making.

In our sky the star Deneb appears fainter than Vega, but it is one of the most luminous stars in our Galaxy. A star's appearance depends on two things: the star's intrinsic brightness and its distance. While Vega is located only 26 light-years away, Deneb shines across a vast distance of more than 1,800 light-years. If Deneb were as close as Vega, it would rival a quarter Moon in brightness, although it would still appear as a point of light! If it were as close to us as our Sun, we'd be blinded by its light and vaporized by its heat.

The third star in the Summer Triangle is Altair, which is closely flanked on either side by a fainter companion. Together this stellar trio is sometimes called the Family of Aquila.

The constellation Aquila is supposed to represent an eagle belonging to Jupiter, the king of gods. In star lore this eagle once swooped to Earth and kidnapped a boy named Ganymede, whom Jupiter wanted as a member of his court.

The star Altair is located only 16 light-years from Earth. It's slightly larger and brighter than our Sun and is notable for its rapid rotation. Our Sun requires over twenty-five days to spin once on its axis; Altair completes a single rotation in just six-and-a-half hours. Calculations show that the star's equatorial diameter should be nearly twice the star's polar diameter as a result. Seen up close, Altair must appear markedly flattened by its own mad spin — a squashed sun in the alien sky of any hypothetical planet.

Through the Eyepiece by Rick Shaffer

SEEING THE SURFACE OF MARS

If you haven't begun observing Mars regularly by now, you really should begin. Mars' apparent diameter grows from 17″ to 22″ this month and the planet's brightness doubles from magnitude −1.5 to −2.3. Mars also rises early enough now that you no longer have to get up at the crack of dawn to view it. At the beginning of the month Mars is above much of the haze and turbulence near the horizon by about 12:30 a.m. local daylight time. By the end of the month you can begin observing the Red Planet as early as 10:30 p.m. local daylight time.

It is now late spring in the planet's southern hemisphere, which is tilted toward both the Sun and Earth. The most prominent Martian feature visible in a telescope is the South Polar Cap, a very thin crust composed mostly of water-ice frost. Because Mars reaches perihelion on August 12 and the southern summer solstice occurs on September 11, the Sun's heat is rapidly melting the frost. Careful observations of Mars or a series of careful scale drawings throughout the apparition should reveal the shrinking polar cap. Observers sometimes confuse the polar cap with the polar hood, a huge cloud of water vapor that sometimes appears over the polar cap and the surrounding area. Because the hood reflects sunlight much as the cap does, it can masquerade as a large polar cap.

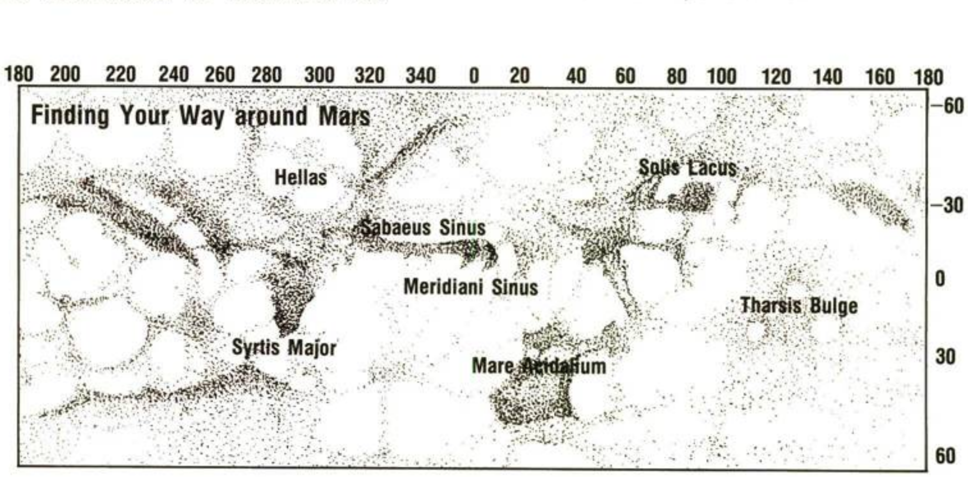
The South Polar Cap remains visible throughout this perihelic opposition. However, to make any systematic observations of other features on the Martian surface, you need to know what Martian longitude is facing Earth when you observe. For that information, see the table below. Mars' day lasts about 37 minutes longer than Earth's, so the face Mars presents for our inspection changes little from day to day. In fact, it takes over a month of viewing Mars at the same time each night to see all the surface features pass the Martian meridian.

The most prominent dark feature on Mars is Syrtis Major, a large, roughly triangular area in the northern hemisphere. In a telescope Syrtis Major often resembles the Indian subcontinent (minus Sri Lanka). At mid-month Syrtis Major is on the Martian meridian for European observers at around midnight, while observers in the Americas will see this feature best at midnight during the last week of the month. If you view Mars at a time when Syrtis Major is expected to be visible and can't find the feature, you may be witnessing one of Mars' infamous dust storms. The worst storms, which can obscure a large fraction of the planet, often occur in the weeks just after perihelion, so August could well be a month of storms. (See "Forecast for Dust Storms on Mars" by Jeff Kanipe on page 76.)

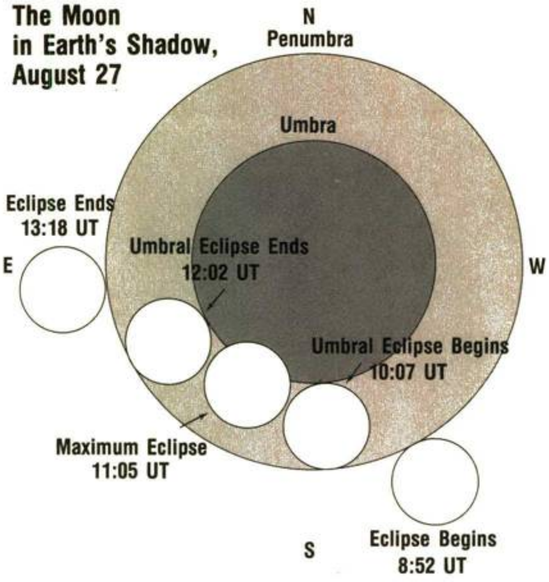
JUPITER AND THE GREAT RED SPOT

As you hone your observing (and drawing) skills on Mars, don't neglect Jupiter. With Jupiter near +20° declination for the rest of the year, this apparition will be a good one for Northern Hemisphere observers. If you begin observing Jupiter regularly now, you'll see more subtle details on the planet's disk as opposition approaches in late November.

Last month I mentioned that the Great Red Spot appears a bit redder than it has for several years. Jim Van Nuland of the San Jose Astronomical Association, a veteran planetary observer and Red Spot watcher, supplied me with the information I needed to produce the transit-time predictions on page 58. These predictions are



Finding Your Way around Mars

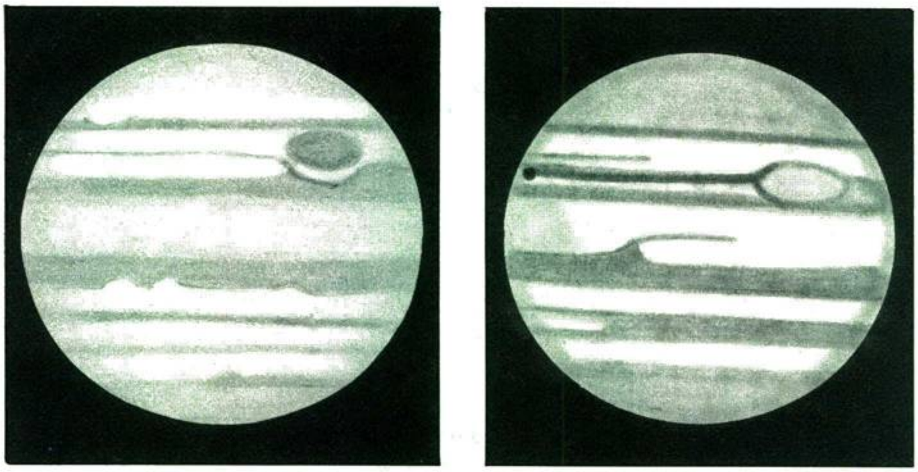


The Moon in Earth's Shadow, August 27

SEEING MARKINGS on the Martian surface is normally quite easy with a telescope. The table below gives the central Martian longitude at 5:00 UT on the date shown (1 a.m. EDT, 10 p.m. PDT the day before). Features are prominent three or four hours before and after this time.

Date	Central Meridian
Aug. 1	107°
Aug. 3	89°
Aug. 5	70°
Aug. 7	51°
Aug. 9	32°
Aug. 11	14°
Aug. 13	355°
Aug. 15	336°
Aug. 17	318°
Aug. 19	300°
Aug. 21	281°
Aug. 23	263°
Aug. 25	245°
Aug. 27	226°
Aug. 29	208°
Aug. 31	190°

based on a model derived from past observations, so they could be off by a few minutes. The Red Spot is visible for about two hours before and after its transit. To allow your eye time to get used to the scene, begin viewing Jupiter at least forty-five minutes before the scheduled transit. The Great Red Spot should appear between the South Temperate Belt and the South Equatorial Belt.



DISTINCT IN SMALL SCOPES during the mid-1960s (left), the Great Red Spot has appeared less conspicuous in recent years (right) and the color has also faded. The table below lists the times of the transits visible to U.S. observers during August and the first letter of the time zones in which each is visible.

Date	Time	Visible in Time Zones
2	3:54 PDT	P
3	2:46 EDT	EC
5	4:24 EDT	ECM
7	3:03 PDT	MP
8	1:54 EDT	E
9	4:41 PDT	P
10	3:33 EDT	ECM
12	2:11 PDT	CMP
13	1:03 EDT	E
14	3:50 PDT	P
15	2:41 EDT	EC
17	4:20 EDT	ECMP
19	2:58 PDT	MP
20	1:50 EDT	EC
22	3:28 EDT	ECMP
24	2:07 PDT	CMP
25	12:58 EDT	E
26	3:46 PDT	MP
27	2:37 EDT	ECM
29	4:16 EDT	ECMP
30	12:07 EDT	E
31	2:54 PDT	CMP

THE MOON IN PARTIAL ECLIPSE

On August 27, the Moon passes through the southern portion of Earth's umbral shadow. The eclipse begins after midnight for observers in the Americas, at mid-evening for mid-Pacific observers, and in the early evening for observers in the Far East and Australia. At maximum eclipse (11:05 UT) Earth's shadow covers 30 percent of the Moon's disk.

Some of the most aesthetically pleasing photographs I've seen are of lunar eclipses, so you might try your hand at photographing this one. However, you can perform an interesting experiment with another photographic tool — the exposure meter. This experiment works especially well with meters that are sensitive only over small angles, such as the so-called "spot meters."

Well before the eclipse begins, mount the meter on the tube of your telescope or on a tripod. Point the meter at the Moon so the entire disk is included in the circle in the meter's reticle. You could also attach a single-lens reflex camera to the low-power eyepiece of your telescope and use the camera's light meter to make the measurements.

Adjust the exposure setting until the meter just deflects from its maximum reading. Then record the meter readings every five minutes, beginning at 8:45 UT and continuing as long as the Moon is visible. Estimate the combination of aperture stop and shutter speed indicated by the meter as accurately as you can.

On the next cloudy night get out your measurements and calculate the relative amount of light reflected by the Moon for each reading you took. This equals the ratio of the measured f/ratio divided by the uneclipsed f/ratio squared, multiplied by the ratio of the uneclipsed exposure time to the measured exposure time.

Once you have done this for all your readings, plot the relative amount of light against the time of your measurement. Your results will look better if you plot them on semilog graph paper, which is available at most drug and stationery stores. When you are finished, you will have a record of the eclipse to save and to compare with future eclipses.

AUGUST'S PLANETS

Mercury reaches superior conjunction on August 3 and spends the remainder of the month lingering so close to the Sun that it is nearly unobservable. By late October and early November Mercury will be well placed in the morning sky.

Although Mars is in the midst of its best apparition in seventeen years, Jupiter and Venus still shine brighter than the Red Planet this month. In August Jupiter takes up a position between the Pleiades and Hyades star clusters in Taurus, where it will remain until November. Its equatorial diameter grows from 37″ to 41″ this month and its brightness from magnitude −2.2 to −2.4.

Having just passed maximum brightness last month, Venus begins August at magnitude −4.4. It rises about three hours before the Sun early in the month, so you'll have to get up early to view its 30″-diameter, "fat crescent" disk. Venus reaches its greatest western elongation from the Sun (46°) on August 22, when it appears like a "half-moon." By the end of the month Venus rises a little less than four hours before the Sun and its slightly gibbous disk has shrunk to 22″ in diameter.

Although Saturn is outshone by three planets this month, the ringed planet does have the grace to be visible in the evening sky. At the beginning of August Saturn sets just as Venus is rising — three hours before sunrise. At month's end, however, Saturn sets just before 1 a.m. local daylight time. Saturn's disk shrinks from 17.8″ to 17.1″ during August and the rings shrink proportionately, from 40.5″ to 38.8″.

Uranus continues to fly in formation with Saturn near the border of Sagittarius and Ophiuchus, never straying more than 2° from the ringed planet. Although the two planets appear close in the sky, Uranus is actually twice as far from Earth as Saturn is. A finder scope or binoculars will easily show Uranus' 5.6-magnitude blue-green disk located just south and east of Saturn all month. But you'll need at least 150x and good seeing to discern the 3.7″-diameter disk of Uranus.

Neptune lies 50 minutes of right ascension east of Saturn all month. To find Neptune's tiny 7.9-magnitude disk, center Saturn in the field of view of a 50x eyepiece. If you have a clock drive, turn it off. Now take a fifty-minute break and look at the sky with binoculars, catch some Perseid meteors, or drink coffee. When you return to the eyepiece, Earth will have slewed your telescope to Neptune. (For those of you who can't wait, scan 50 minutes of right ascension east of Saturn.) Then increase the magnification to view the blue-green planet. As with Uranus, you'll need high power for a clear view of Neptune's 2.3″-diameter disk.

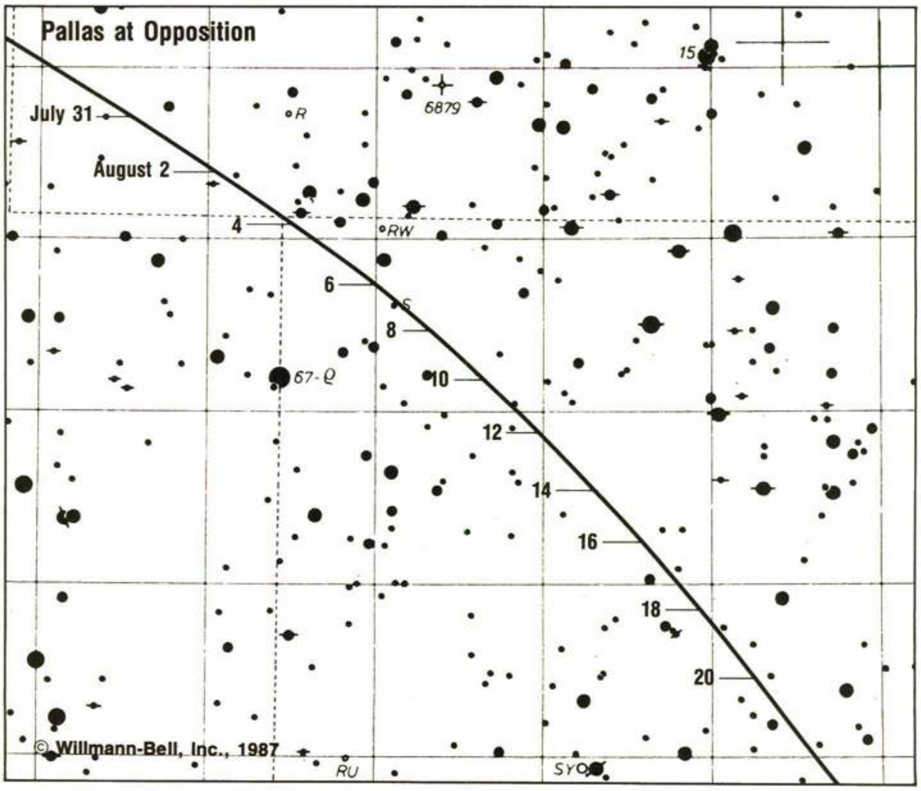
AUGUST'S COMETS

The year's most promising periodic comet becomes bright enough for viewing in small- to moderate-sized telescopes this month. Comet Tempel 2 — approaching perihelion on September 16 — is in Libra at the beginning of the month but passes through northern Scorpius at mid-month and into Ophiuchus by the end of August. Make Tempel 2 your first target each evening, as it is well past the meridian at the end of astronomical twilight. Use the finder chart in July's Through the Eyepiece to find Tempel 2 this month.

AUGUST'S ASTEROIDS

The first two asteroids to be discovered are well placed for observing this month. Asteroid 2 Pallas reaches opposition on August 2 in Sagitta but moves into Aquila for the rest of the month. Locate this 9.6-magnitude asteroid with the help of the chart at right.

Asteroid 1 Ceres reaches opposition in September and is fairly bright (magnitude 7.7) this month in Cetus. To find Ceres, plot its position (see the table at right) on an atlas such as *Uranometria 2000.0*. Then sketch the field at your telescope using at least 100x and observe the same field the next night. The "star" that moved is Ceres.



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FIND THE TWO LARGEST ASTEROIDS during the dark of the Moon this month. Both Ceres and Pallas are well placed for telescopic viewing in August.

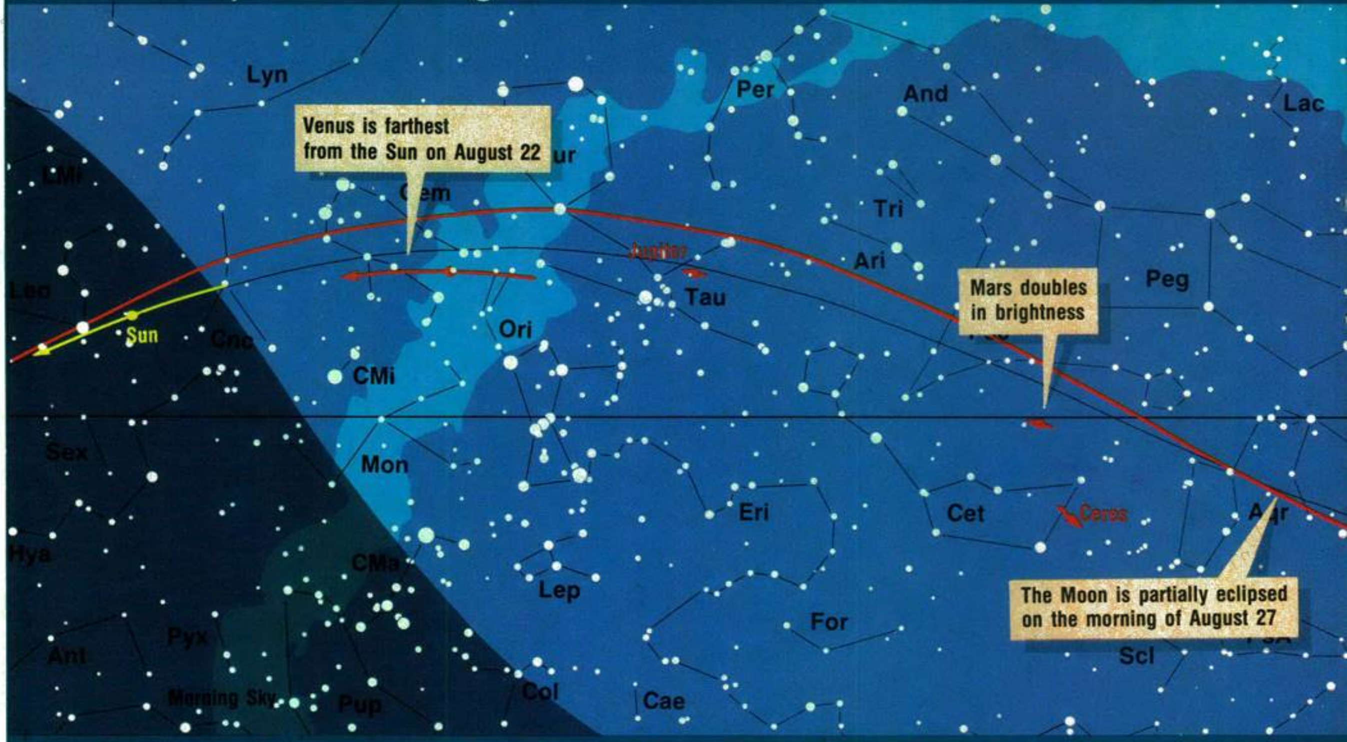
Ceres

	R.A. (2000)	Dec.
Aug. 2	0h29.0m	−12°10′
Aug. 8	0h28.5m	−12°40′
Aug. 14	0h27.2m	−13°13′
Aug. 20	0h25.1m	−13°50′
Aug. 26	0h22.2m	−14°28′
Sept. 1	0h18.6m	−15°06′

Pallas

	R.A. (2000)	Dec.
Aug. 2	20h15.7m	16°18′
Aug. 8	20h11.1m	15°27′
Aug. 14	20h06.8m	14°29′
Aug. 20	20h03.0m	13°25′
Aug. 26	19h59.7m	12°17′
Sept. 1	19h56.9m	11°05′

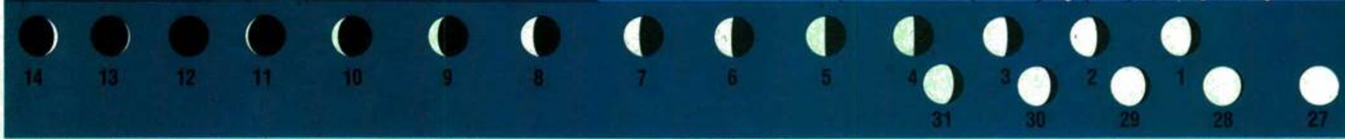
The Solar System August 1988


Lyn
LMi
Leo
Sun
Cnc
Gem
Per
And
Lac
Tri
Ari
Jupiter
Tau
Peg
Ori
CMi
Mon
Sex
Hya
CMa
Lep
Eri
Cet
Ceres
Aqr
For
Pyx
Ant
Morning Sky
Pup
Col
Cae
Scl

Venus is farthest from the Sun on August 22

Mars doubles in brightness

The Moon is partially eclipsed on the morning of August 27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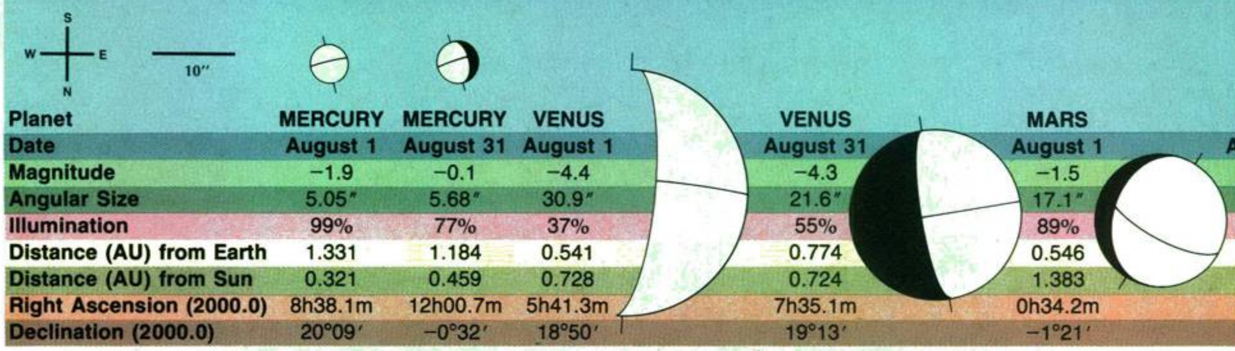
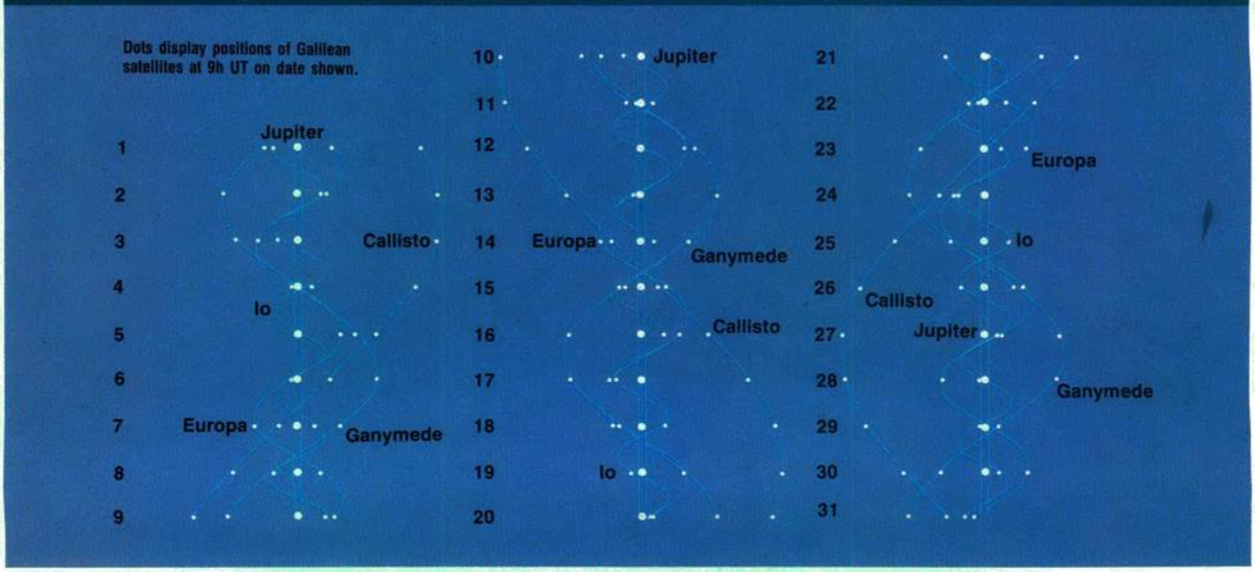
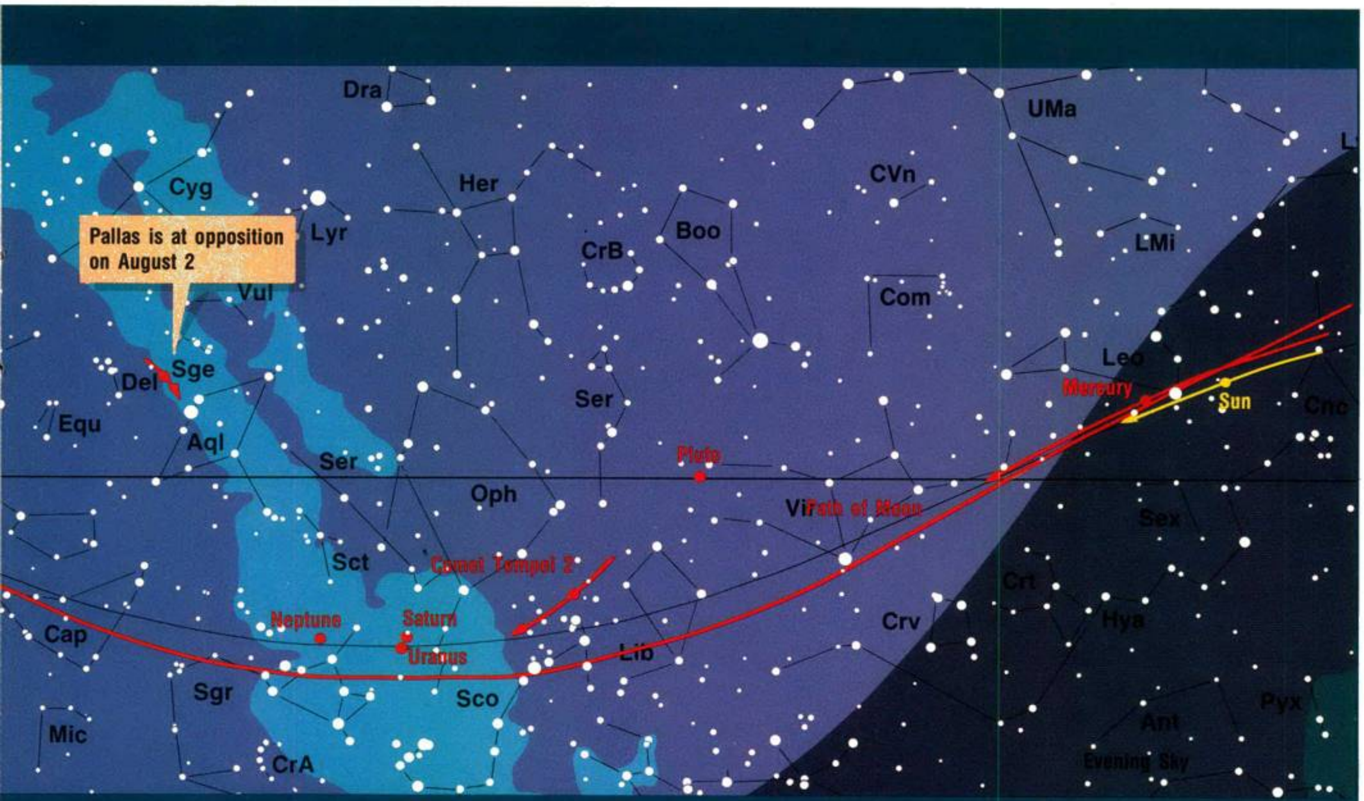


Planet	MERCURY	MERCURY	VENUS	VENUS	MARS	MARS
Date	August 1	August 31	August 1	August 31	August 1	August 31
Magnitude	−1.9	−0.1	−4.4	−4.3	−1.5	−2.3
Angular Size	5.05″	5.68″	30.9″	21.6″	17.1″	21.9″
Illumination	99%	77%	37%	55%	89%	96%
Distance (AU) from Earth	1.331	1.184	0.541	0.774	0.546	0.426
Distance (AU) from Sun	0.321	0.459	0.728	0.724	1.383	1.384
Right Ascension (2000.0)	8h38.1m	12h00.7m	5h41.3m	7h35.1m	0h34.2m	0h50.5m
Declination (2000.0)	20°09′	−0°32′	18°50′	19°13′	−1°21′	−0°20′

Jupiter's Moons



Dots display positions of Galilean satellites at 9h UT on date shown.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Pallas is at opposition on August 2
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Sun
Cnc
Equ
Ser
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Pluto
Ser
Oph
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Path of Moon
Sex
Sct
Comet Tempel 2
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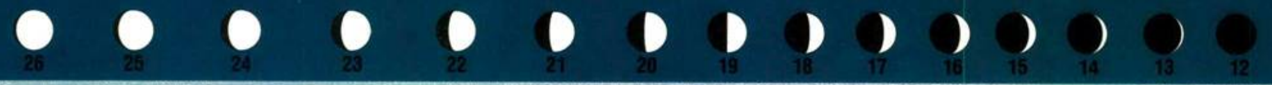
CrA
Evening Sky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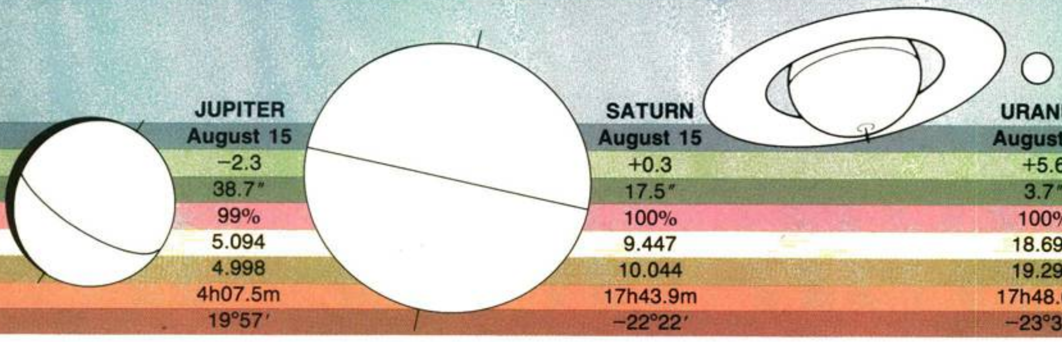
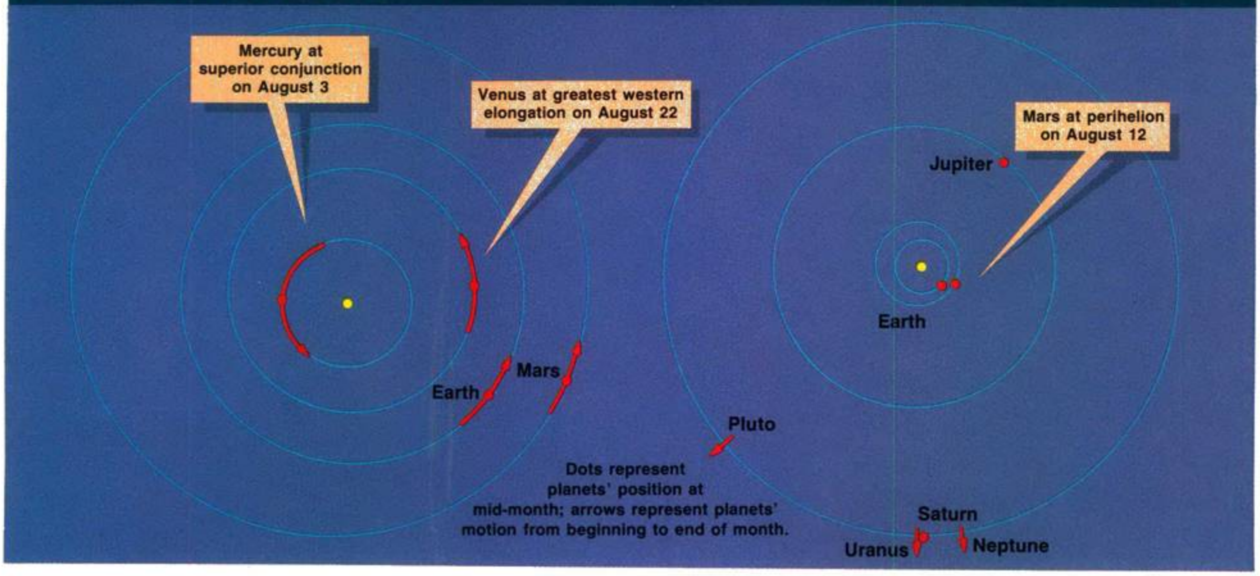


JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
August 15	**August 15**	**August 15**	**August 15**	**August 15**
−2.3	+0.3	+5.6	+7.9	+13.7
38.7″	17.5″	3.7″	2.3″	0.1″
99%	100%	100%	100%	100%
5.094	9.447	18.693	29.494	29.856
4.998	10.044	19.290	30.223	29.663
4h07.5m	17h43.9m	17h48.6m	18h34.1m	14h51.1m
19°57′	−22°22′	−23°38′	−22°14′	0°13′

The Planets in Their Orbits


Mercury at superior conjunction on August 3
Venus at greatest western elongation on August 22
Mars at perihelion on August 12
Jupiter
Earth
Mars
Earth
Pluto
Saturn
Uranus
Neptune

Dots represent planets' position at mid-month; arrows represent planets' motion from beginning to end of month.

CHALLENGER
7
CRIPPEN
FABIAN
HAUCK
RIDE
THAGARD

STS 7
Enlarged
to show
detail.

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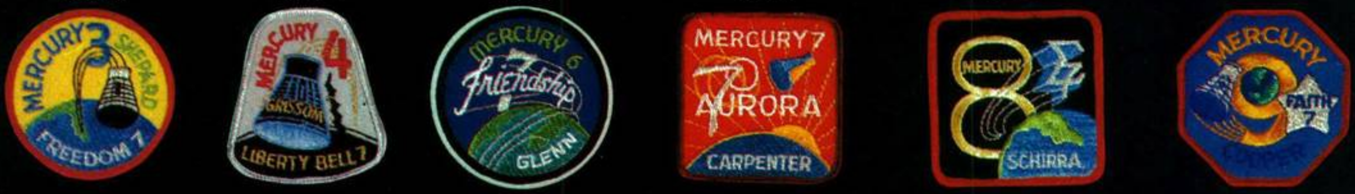
MERCURY 3
SHEPARD
FREEDOM 7
MERCURY 4
GRISSOM
LIBERTY BELL 7
MERCURY 6
friendship 7
GLENN
MERCURY 7
AURORA
CARPENTER
MERCURY 8
SCHIRRA
MERCURY 9
FAITH 7
COOPER

MER 3 MER 4 MER 6 MER 7 MER 8 MER 9

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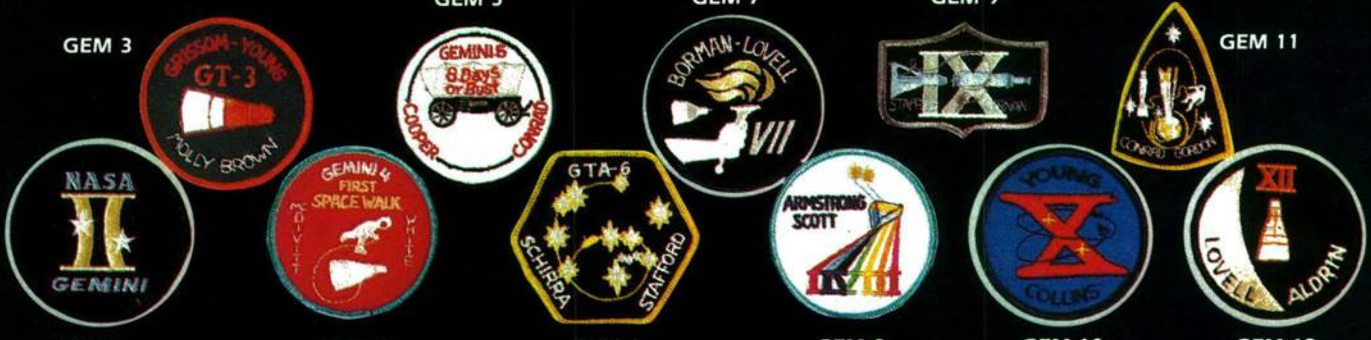
GRISSOM-YOUNG
GT-3
MOLLY BROWN
NASA
II
GEMINI
GEMINI 4
FIRST SPACE WALK
McDIVITT
WHITE
GEMINI 5
8 Days or Bust
COOPER
CONRAD
GTA-6
SCHIRRA
STAFFORD
BORMAN-LOVELL
VII
IX
STAFFORD
CERNAN
ARMSTRONG
SCOTT
VIII
YOUNG
X
COLLINS
CONRAD
GORDON
XII
LOVELL
ALDRIN

GEM 3 GEM 5 GEM 7 GEM 9 GEM 11

GEM GEM 4 GEM 6 GEM 8 GEM 10 GEM 12

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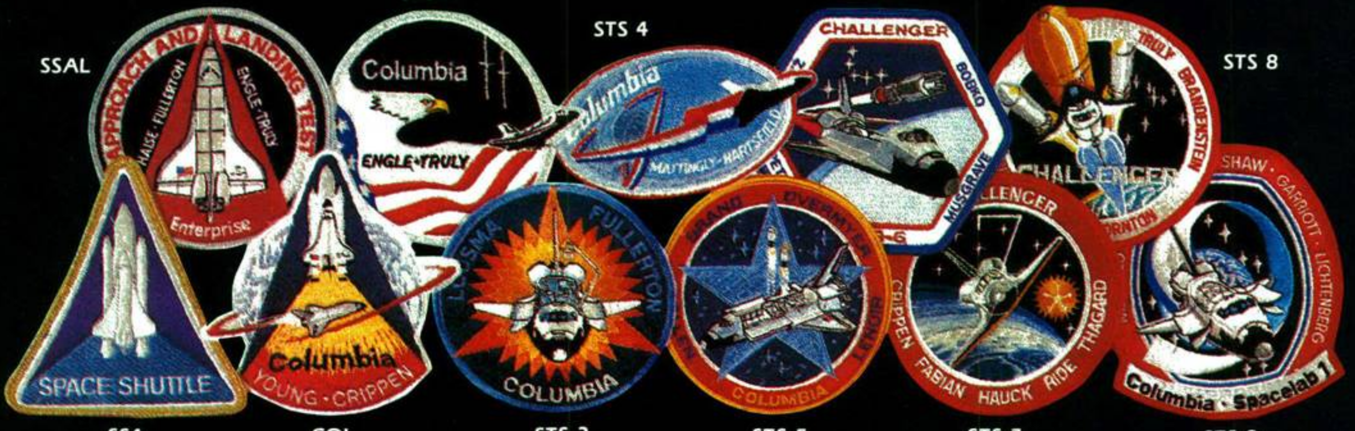
SSAL STS 4 STS 8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ENGLE · TRULY
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ENGLE · TRULY
Columbia
MATTINGLY · HARTSFIELD
CHALLENGER
BOBKO
MUSGRAVE
6
TRULY
BRANDENSTEIN
CHALLENGER
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SPACE SHUTTLE
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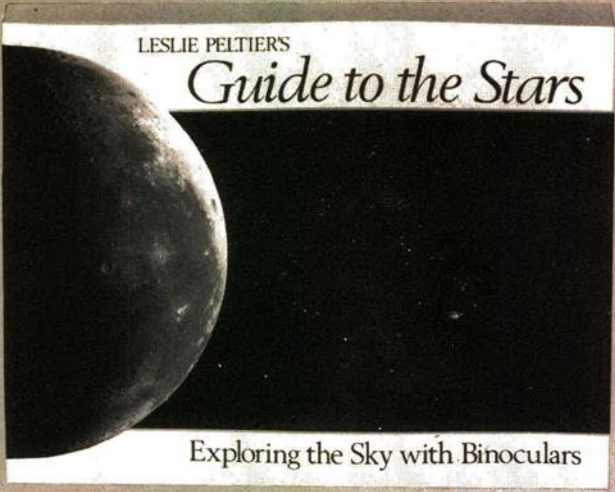

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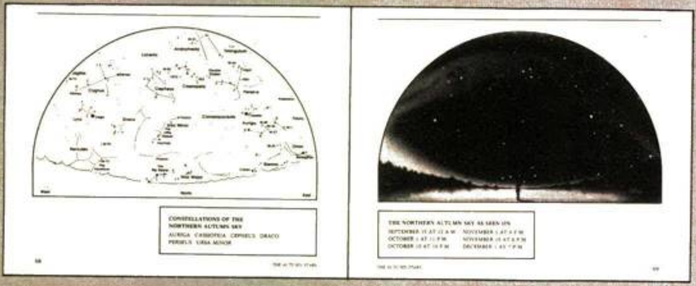

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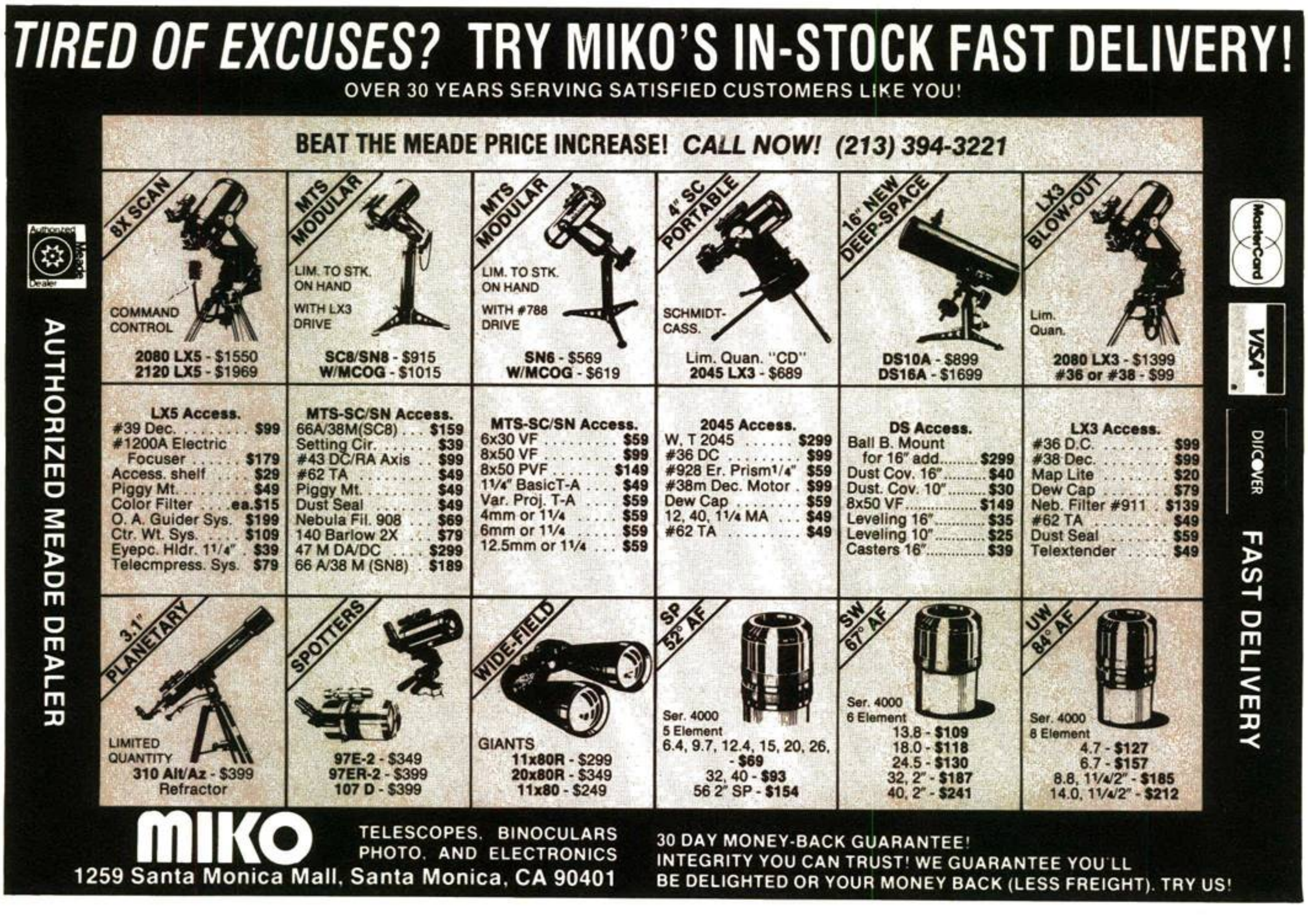

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The Mount of Gibraltar

Make your telescope mount as solid as a rock by filling the tripod head with epoxy resin and adding leg braces.

by Rick Shaffer

You touch the focus knob and the star dances across the field of view. Or you turn the slow-motion control to recenter a tiny crater and ten seconds later the image finally settles down. Sound familiar? More telescopes are packed away in the attic because of wiggly tripods than because of bad optics. Luckily, you can coax substantially better performance from many of these shaky-limbed optical gems for about $35 and a few hours of spare time.

The secret is two simple modifications: stiffening the joint where the tripod legs attach to the equatorial head assembly and adding braces to keep the tripod legs firmly in place when spread for use.

I have a Polaris equatorial mount for my 5.5-inch Schmidt-Newtonian. It is by no means a bad mounting, but its performance can certainly be improved. It is also similar in design to most other wooden-tripod mountings and therefore the same bag of tricks I used to upgrade my Polaris can help tune up similar mountings as well.

The modifications are unquestionably effective: they can reduce the vibration of an object viewed at high power by roughly a quarter and halve the time the tremors take to stop. For example, a friend of mine has an 8-inch Schmidt-Cassegrain on a Super Polaris mount. He noticed that at 400x a star would vibrate across 40 percent of the field of view when he touched the slow-motion knob to center the star and that the vibrations took about ten seconds to fade away. After modification the vibrations covered 10 percent of the field and died out in three or four seconds. Worth it? You bet.

Let's begin by clearing a space in which to work. You should have a smooth, hard floor and good ventilation. A patio, breezeway, or garage is ideal, but a basement will also suffice, provided you can air it thoroughly.

PARKS
Acetone
PC-7
B
PC-7
A
Epoxy

SIMPLE HARDWARE AND A FEW HOURS OF WORK can make that shaky telescope mounting perform far better than it did when new.

First, remove the telescope from the cradle, unscrew the counterweight and slow-motion controls, and turn the tripod over. (An old sheet folded up on the floor will prevent scuffs.) Now look carefully at how the wooden legs are attached to the tripod head, a relatively thin-walled aluminum casting.

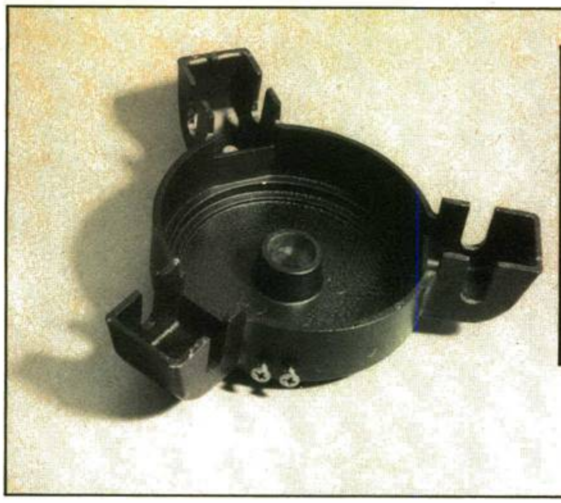
Note that each leg is held to the tripod head by a bolt that passes through both sides of the casting and that is tightened with a large wing nut. Note, too, that on the Polaris (and many other mountings) the bolt "hole" in the casting is actually an open-bottom slot.

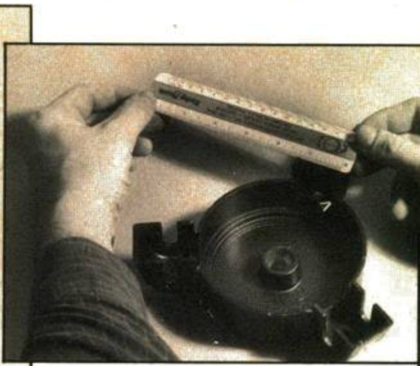
This creates two problems. The first is that tightening the wing nut to hold the leg more firmly merely squeezes and deforms the casting. (The little gusset is no help because it stops short of the casting's edge.) The inevitable result is that no matter how much you tighten those wing nuts, you can never make the legs really *lock* onto the tripod head. The second problem is that if you loosen the nuts too far, the open-bottom slots let the legs fall out on the ground.

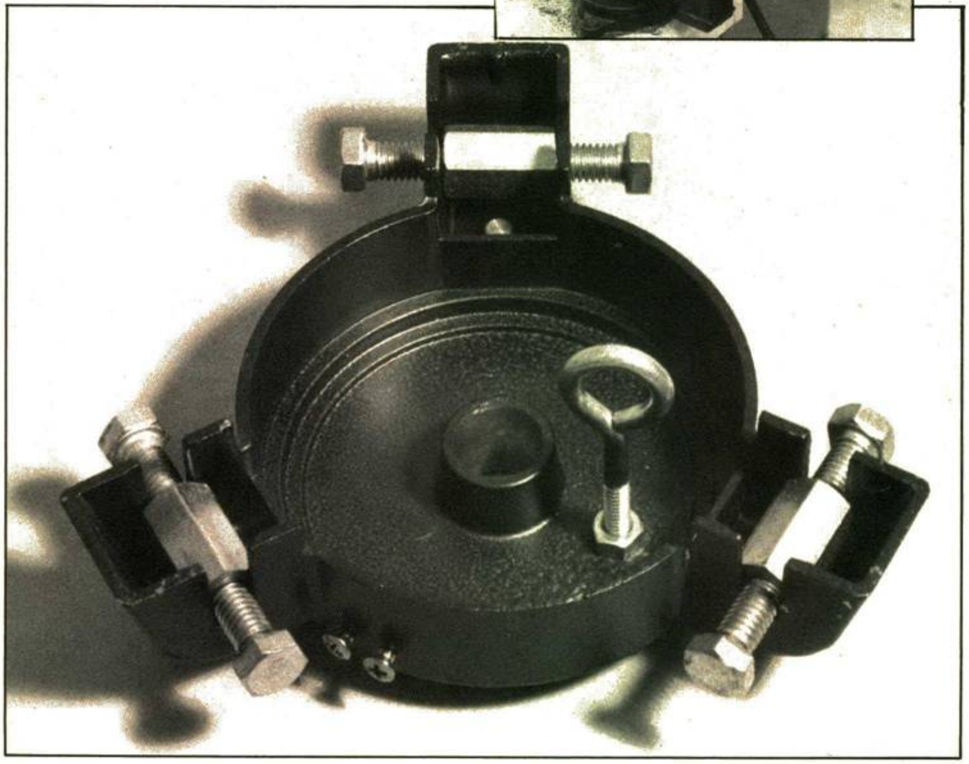
Our solution, therefore, will be to fill the head with epoxy resin so it becomes a solid casting, which allows the tripod legs to be tightened to extreme rigidity. Second, we will incorporate threaded steel inserts, called bolt connectors or joiners, into the casting so there is no danger of the tripod coming apart unexpectedly.

The materials for the project are listed in the box on page 68. But before you head off to the hardware store, give a moment's thought to which kind of epoxy resin you wish to use. The choice comes down to either the messy (yet very strong) liquid metal and concrete filler or the tidier (but a bit weaker) plumber's putty.

For my own scope, I chose the pourable metal and concrete filler, in part







MEASURING AND CUTTING

Strip down the tripod head but leave any screws piercing the casting in place so the holes don't fill up. Measure the slot's width carefully at the top and at the bottom because the slot may taper. After you hacksaw the bolt connector to length, file it to fit the slot. With the connectors (and optional eyebolt) in place, wipe down the inside with acetone to remove grease.

because eight years ago I used the stuff to glue a broken concrete picnic table together and the repair is still intact. But if you want to go with putty to avoid the mess, it will be strong enough. One caution, however: If you are allergic to epoxy resin or you find that the resin simply smells too bad to put up with, this project is not for you. And epoxy resin *does* stink — which is why you need a well ventilated place to work in.

Preparing the Casting

To prepare the casting, first disassemble the tripod. Remove the equatorial head by unscrewing the large bolt that fastens it to the tripod head. This bolt usually passes through the tripod casting from below and mates with a threaded hole in the underside of the equatorial head. (To preclude losing the bolt, screw the bolt back into the equatorial head once the head is detached.)

Next, remove the legs from the tripod by loosening the wing nuts and slipping each leg out of its slot. On tripods that are not slotted, remove the bolts completely. Now wipe the interior of the tripod head casting with a paper towel moistened with acetone or fingernail polish remover. This removes grease, which will prevent good adhesion between the epoxy and the casting. Work in a well-ventilated area and be careful not to slop large amounts of acetone on the casting; it will ruin the paint.

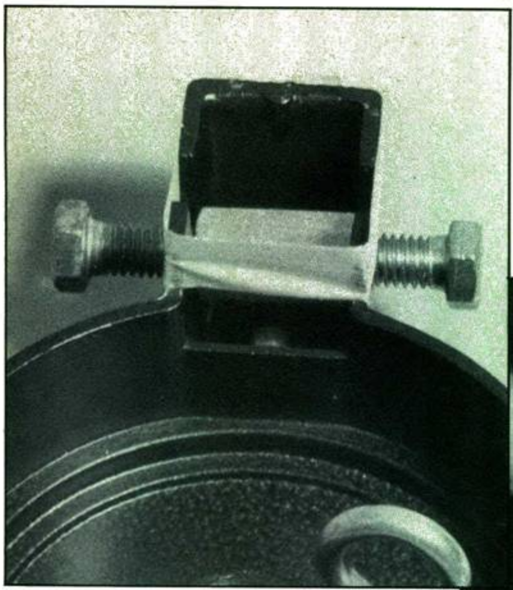
Measure the interior width of the casting at the slot. With a hacksaw, cut the bolt connectors to length so each one fits tightly inside the casting. (You'll probably have to file the cut end of each connector to make the connector fit smoothly.) Then fix the connectors in place with a bolt at each end. Check that the bolt connectors are lined up square and straight. Last, clean the connectors with acetone to remove grease.

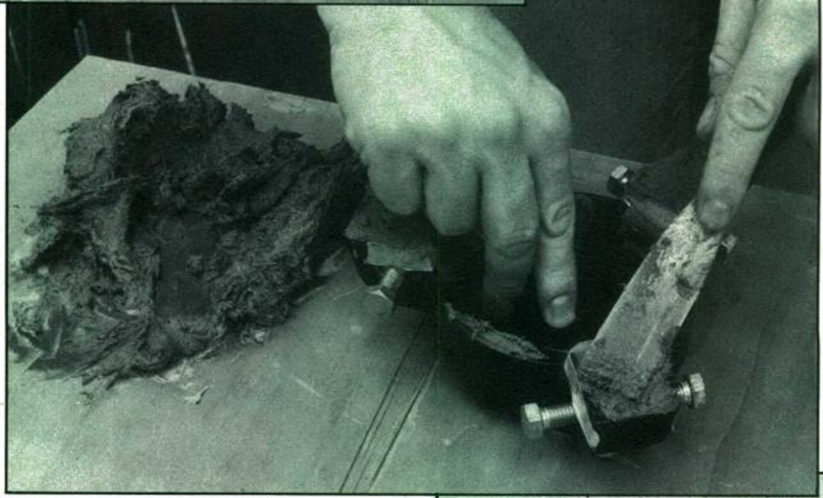
The tripod head is now almost ready to be filled with resin. But before you continue, consider one other modification. If you take astrophotos with the mounting, you can gain some useful extra stability by hanging weights from the underside of the tripod head — hence the eyebolt you see in some of the pictures. (For visual observing the increase in stability is nice to have but less important.)

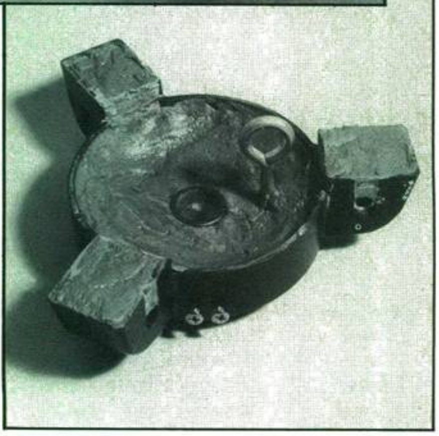
To mount the eyebolt, drill a 1/4" hole a little off-center in the flat top of the casting. Align the eyebolt with the north leg of the tripod. The eyebolt attaches with two 1/4" nuts that sandwich the casting between them.

Make sure the threaded end of the eyebolt does not protrude above the upper nut. This ensures that the equatorial head will clear the end of the eyebolt when you reinstall the head on the tripod. In any case, check that the equatorial head fits back in place *before* you fill the casting with epoxy!

The last step of preparation is to dam the casting with reinforced packaging or duct tape, so the epoxy won't overflow. (If you plan to use putty, you can omit this step.)







FILLING WITH EPOXY

Packing the tripod head with epoxy takes three steps. First, construct tape dams to confine the epoxy. Then thoroughly mix the resin's two components on a scrap of wood. Finally, scoop the epoxy into the tripod head. After the epoxy has set overnight, remove the tape and clean up the rougher edges.

Pouring Metal and Concrete Filler

Open the cans containing the resin and the hardener. This stuff is not pure epoxy; rather, it contains epoxy and inert filler material. You should assume that the filler material has separated and sunk to the bottom, so blend the contents of each can thoroughly with a paint stirrer made of scrap wood. (Popsicle sticks are ideal.) Use two stirrers, one for each can. Then mix the two ingredients together according to the directions on the package, paying special attention to mixing them thoroughly. Do your mixing on a piece of scrap wood at least 6 inches square.

Hold the tripod head securely upside down on your work surface and make sure it is level. *To fill* the casting with resin, I found that scooping up blobs of material with a small putty knife or old screwdriver and letting the material flow into the casting worked reasonably well. (I also found patience a virtue here, because the stuff flows pretty slowly.) For maximum rigidity, make sure every cavity is filled and that there are no air bubbles. Finally, clean any messed-up areas with acetone and let the epoxy set overnight.

Tamping In Plumber's Putty

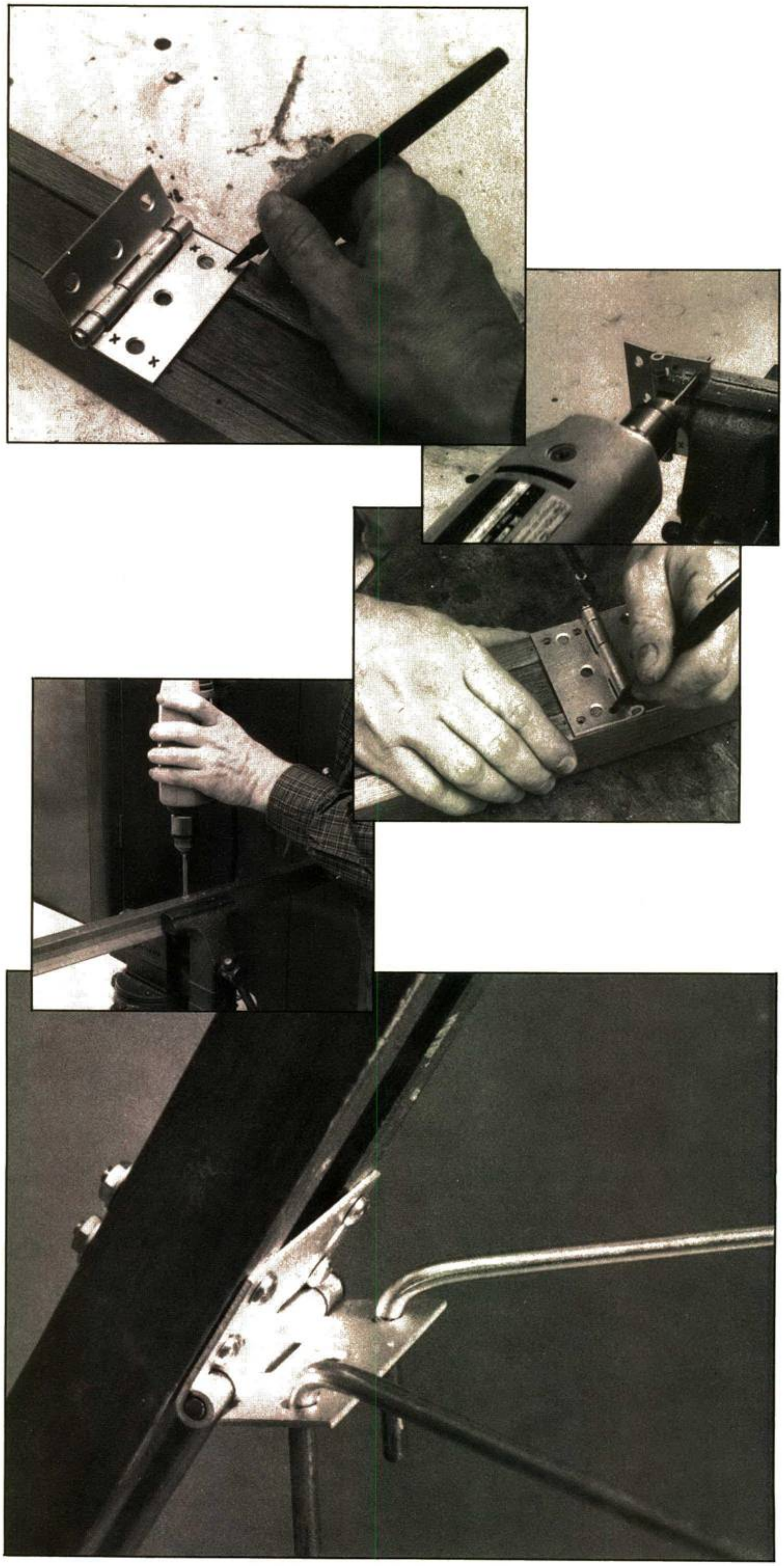
Putty is cleaner to work with, but it can irritate your hands, so wear disposable rubber gloves while you work it. The putty comes in sticks approximately 3/4'' by 1-1/2'' by 8'' in size. For most tripods one package will suffice, but to be safe, buy two and return the second if you don't need it.

Wait for a warm day to mix the putty. I recommend placing the unopened package out in the Sun for half an hour before you begin mixing. Even in its softened state the putty is fairly stiff, so cut off only an inch of part A and part B at one time. I found it best to work the putty like taffy — pulling it out in strings and twisting the strings around and around one another.

After mixing each batch, firmly knead the putty down into the casting with a piece of dowel or scrap wood. Work it into every nook and cranny. Kneading ensures that all the crevices are filled and that each new batch will adhere to the previous one. Take special pains to encase the bolt connectors completely. When this is done, let the putty set overnight.

BRACING THE LEGS

Stiffening the legs requires rigid braces. Begin by marking one side of each hinge for new bolt holes, and then drill the holes, making small "pilot" holes first. Use each hinge as a template for locating the bolt holes in the tripod leg. Drill the holes in the legs and attach the hinges. Install the bent-rod braces and you're ready to go.



Even after setting, epoxy remains slightly tacky. You can eliminate this by curing it overnight in an oven set to 190° F. (Be sure, however, to keep the room windows open and force ventilation with a fan. Also, don't cure the casting until it has already set overnight at room temperature.) Curing isn't necessary for improved telescope performance — it's just for neatniks.

When you reattach the legs with the new bolts, place a fender washer between each leg and the casting as well as between the leg and the head of the bolt. (If the new bolts won't slide through the tripod leg, enlarge the holes a little.) The washers ensure that the wooden tripod legs hold rigidly to the tripod head. They will also distribute the force of the bolts so the bolts don't crush the wood right next to the holes. Tighten the bolts until each leg can be moved by hand, but leave the movement quite stiff.

Want to Go the Whole Enchilada?

The Polaris mounting and many other makes of tripods come with an eyepiece tray that also functions as a leg brace. Unfortunately, these trays have a couple of drawbacks. First, they are not as sturdy a brace as you need, and second, they encourage you to leave eyepieces out where the dew will soak them (instead of keeping them in a storage box). I made new braces from 1/4" rods that are collapsible but that hold the legs rigidly in place.

Remove the old eyepiece tray/brace and detach its hardware from the tripod legs. On each leg, measure and mark a point halfway between the upper and lower ends of the fixed outer pieces. (If your tripod legs have a metal band across the middle, place the mark just below it.)

The hinges come predrilled for screws, but the holes are not placed correctly for the four bolts that hold the tray to the tripod leg. Find and mark four places where you can drill new holes 3/16" in diameter. Use a punch to mark the place and use your smallest drill for a pilot hole. Follow this with the 3/16" hole. When you have drilled the holes, place the hinge on the tripod leg and mark the bolt holes on the wood. When you drill through

MATERIALS YOU'LL NEED

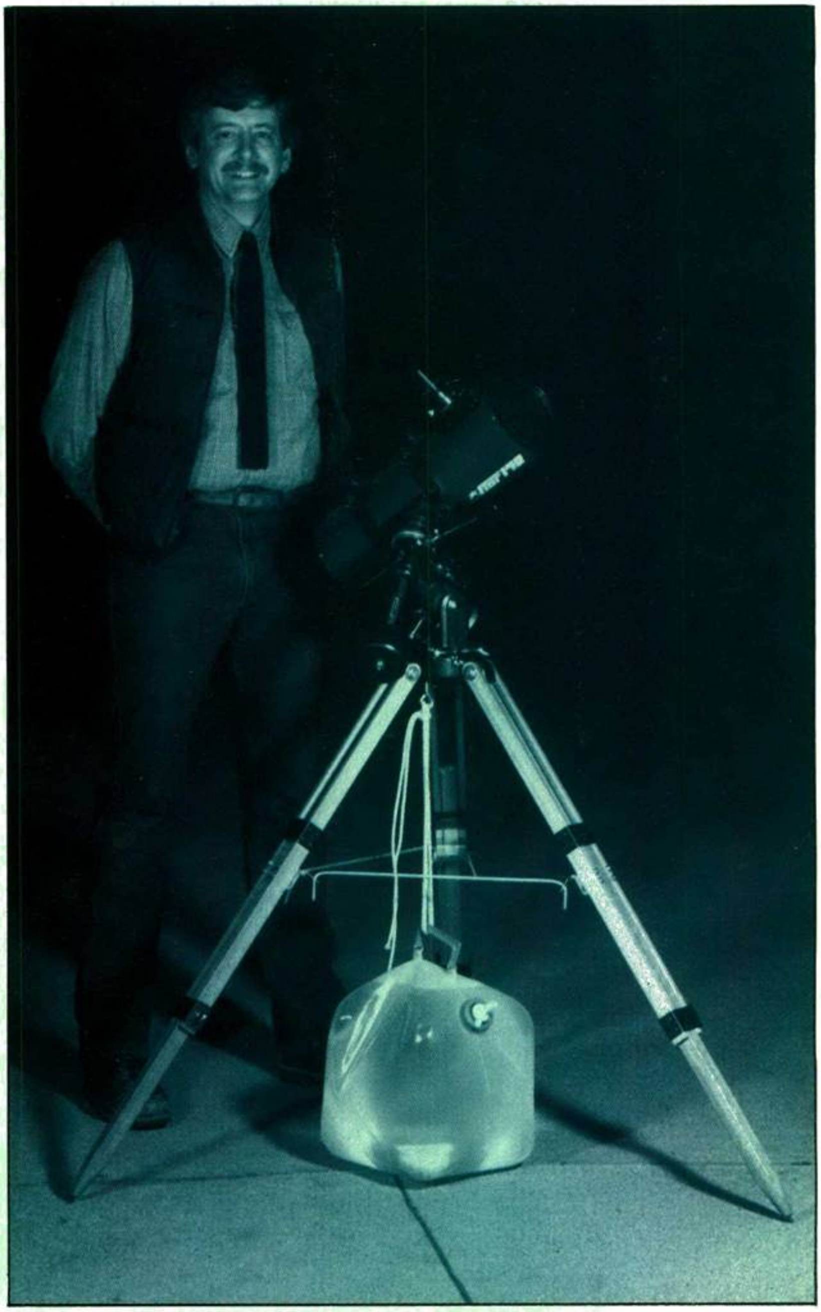
At your local hardware store, obtain the following:

3	3/8″, 16 threads-per-inch bolt connectors (joiners)
6	3/8″, 16 threads-per-inch by 1-1/4″ machine bolts
12	3/8″ by 1″ diameter fender washers
1	2″ long by 1/4″ eyebolt plus an extra 1/4″ nut
1	12-ounce can of epoxy concrete and metal filler
or	
2	packages of epoxy plumber's putty
*3	3″ aluminum hinges, tight pin
*12	#10 by 24 threads-per-inch by 1-3/4″ machine bolts
*12	#10 washers
*12	#10 by 24 threads-per-inch nuts
*3	pieces of 1/4″-diameter mild steel rod, each 18″ long

Buy the items marked with an (*) only if you intend to replace the leg braces on your tripod with those described in the text.

In addition to those listed above, you will need the following items, most of which can be found around the house:

Small bench vise
3/8″ electric drill and bits
Hacksaw
Metal file
6″ ruler
Screwdriver
Putty knife
6″ adjustable wrench
Small can of acetone or fingernail polish remover
Roll of 1/2″ nylon-reinforced strapping tape
Painter's stirring sticks
Disposable rubber gloves
Rags or a roll of paper towels
Old newspapers



FOR EXTRA STABILITY Rick Shaffer hangs a full plastic water bag from the eyebolt.

the wood (also using the 3/16″ drill), be careful to send the drill straight into the wood. Also make sure that you locate the holes for the screws so they will not impede each leg's sliding center piece.

You may also need to enlarge two screw holes on the free end of the hinge. Drill or ream them out to a diameter of 9/32″. This is large enough that the 1/4″-diameter rods fit reasonably tightly, yet you can remove them when you fold the tripod.

The hinges attach to the inside of each leg with machine bolts, not wood screws. (The wood commonly used for tripod legs is not strong enough to give a tight and long-lasting fit with screws.) Do not omit the washers, because they prevent the wood from crushing when you tighten the bolts.

With a hacksaw, cut the 1/4″ steel rod to 18″ lengths. Clamp the last 1-1/2″ of one end in a bench vise. Grasp the rod as close to the vise as you can with one hand and about halfway up the rod with the other hand. Bend it 90°, making the bend fairly tight. (If you are unable to bend the rod by hand, use a Channel-Lok or Vise-Grip as a lever.) Then unclamp the rod and do the same to the other end, making sure both bends lie in the same plane. (The result should resemble an oversized staple.) Now bend the other two rods to match the first. The pieces should be as identical as possible, but so long as the middle sections are all within a quarter inch of the same length, it will be okay.

When you reassemble your "new" tripod, you'll be astonished by how much its performance has improved. No longer will objects leap and sway uncontrollably when you touch the mounting. If some old telescope is sitting around your house, neglected, take a little time and tune up its mounting. I bet you'll find there are years of pleasure still left in it. ☐

Rick Shaffer is chief of the Operations Planning and Control Team for the Magellan *Project at the Jet Propulsion Laboratory in Pasadena. He notes that the idea of filling the tripod casting with epoxy was suggested by Steve Greenberg of the San Jose Astronomical Association.*

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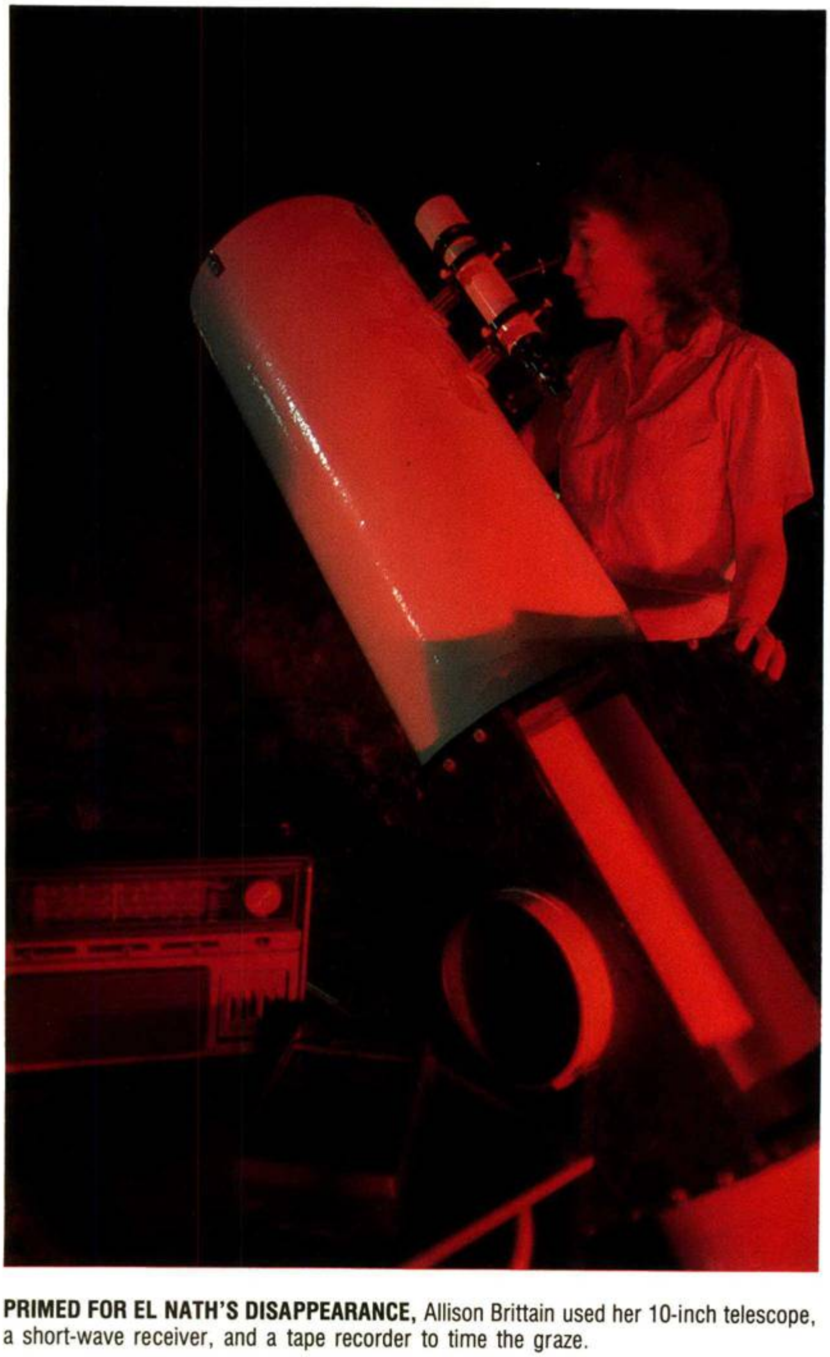
Charting Mountains on the MOON

Two Texas astronomy clubs observed a grazing occultation and used their data to map mountain peaks along the lunar limb.

by Robert Reeves, Ron Dawes, and Rick Frankenberger



PRIMED FOR EL NATH'S DISAPPEARANCE, Allison Brittain used her 10-inch telescope, a short-wave receiver, and a tape recorder to time the graze.

The wait seemed endless. Then, without any warning, the star blinked out. After a few seconds of darkness the star suddenly blinked back on.

Eighteen of us were watching El Nath, the second brightest star in the constellation Taurus, as it skimmed the northern edge of the Moon. But what we were actually seeing was the shadow of the Moon's limb as it passed over southern Texas. By carefully coordinating the observations, our group was helping to chart a poorly explored region of the Moon.

That was why we had joined other members of the San Antonio Astronomical Association and the Randolph Area Amateur Astronomers in an expedition to watch El Nath graze the Moon on October 12, 1987. The relative ease with which the two groups carried out the seemingly complex expedition prompted us to share the experience. It's the perfect type of project for groups of amateur observers to participate in, and the observations help extend our knowledge of Earth's nearest neighbor.

Grazing the Moon's Surface

As the Moon orbits Earth, it occasionally passes in front of a bright star and blocks, or occults, the star's light. Because the Moon is so much closer to Earth than the star is, viewers at different locations see a lunar occultation from different perspectives.

From one point on the globe the Moon may pass directly in front of the star, while from another point the Moon may miss the star entirely. However, for viewers located in a very narrow band, the star appears to skim the edge of the Moon, playing hide-and-seek behind the lunar mountains and hills. This effect is called a grazing occultation.

In recent years a branch of lunar science has evolved that takes advantage of the mobile observing capabilities of amateur astronomers to observe grazing occultations. The International Occultation Timing Association (IOTA) leads the worldwide effort to systematically observe these events and to extract new lunar data from them.

IOTA calculates when and where grazing occultations will be visible and disseminates the information to its members, who then organize expeditions to view those grazes that occur close to where they live.

Astronomers use grazing occultations in a variety of ways. First of all, the observations yield a detailed profile of the limb of the Moon that the star passes behind. The polar regions of the Moon are probably the least studied area of the lunar surface.

In addition, grazing occultations help astronomers refine the polar diameter of the Moon and study characteristics of the occulted star. Because the Moon's orientation changes slightly as the Moon orbits Earth — an effect called lunar libration — each occultation exposes a different edge of the Moon so that new data about the Moon can be collected.

Amateurs Are the Key

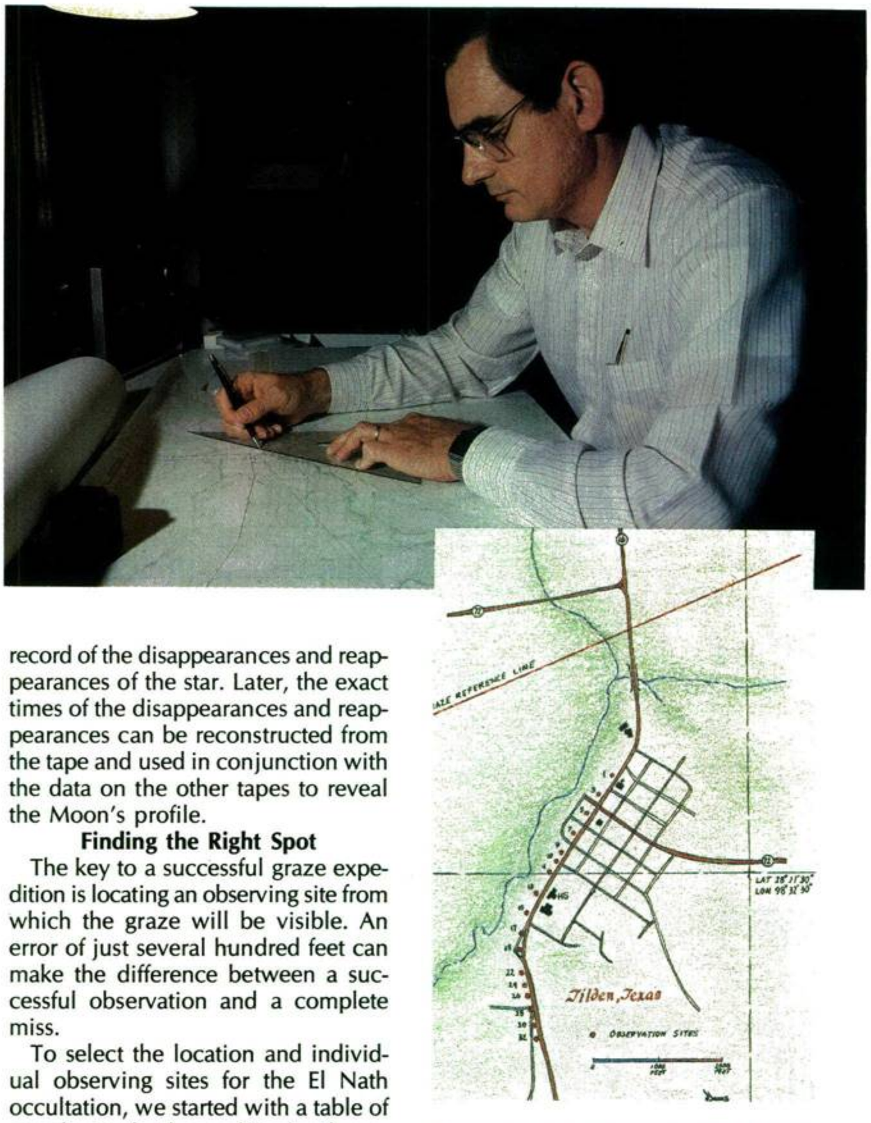
Graze observations are uniquely suited to the capabilities of hobby astronomers. With portable telescopes and flexible schedules, amateurs can generally travel to the right place and be there at the right time, while professional astronomers with their permanently mounted telescopes cannot.

Observing grazing occultations is a perfect project for an astronomy club with a large number of portable telescopes. The only additional equipment needed is portable tape recorders and short-wave radios that can pick up the time signals from station WWV at 2.5, 5, or 10 MHz.

The basic technique is quite simple. Observers set up their telescopes at regular intervals along a line as nearly perpendicular to the predicted graze path as possible. Because the Moon travels west to east relative to the stars, the graze path also runs generally west to east, and thus observers are spaced evenly along a north-south line that averages about a mile long.

As the Moon's edge passes in front of the star, observers at one end of the line see the star disappear behind the broad base of lunar hills or even behind the body of the Moon. Observers farther up the line see the star pass behind progressively narrower portions of the Moon's mountaintops until, potentially, observers at the opposite end of the line may see the Moon miss the star completely.

With a tape recorder running throughout the occultation, each observer records the time signals from WWV along with his or her verbal record of the disappearances and reappearances of the star. Later, the exact times of the disappearances and reappearances can be reconstructed from the tape and used in conjunction with the data on the other tapes to reveal the Moon's profile.



PLOTTING THE OCCULTATION'S PATH, Rick Frankenberger (top) begins the task of pinpointing the observing sites. The sites fell along the major road in Tilden, Texas.

Finding the Right Spot

The key to a successful graze expedition is locating an observing site from which the graze will be visible. An error of just several hundred feet can make the difference between a successful observation and a complete miss.

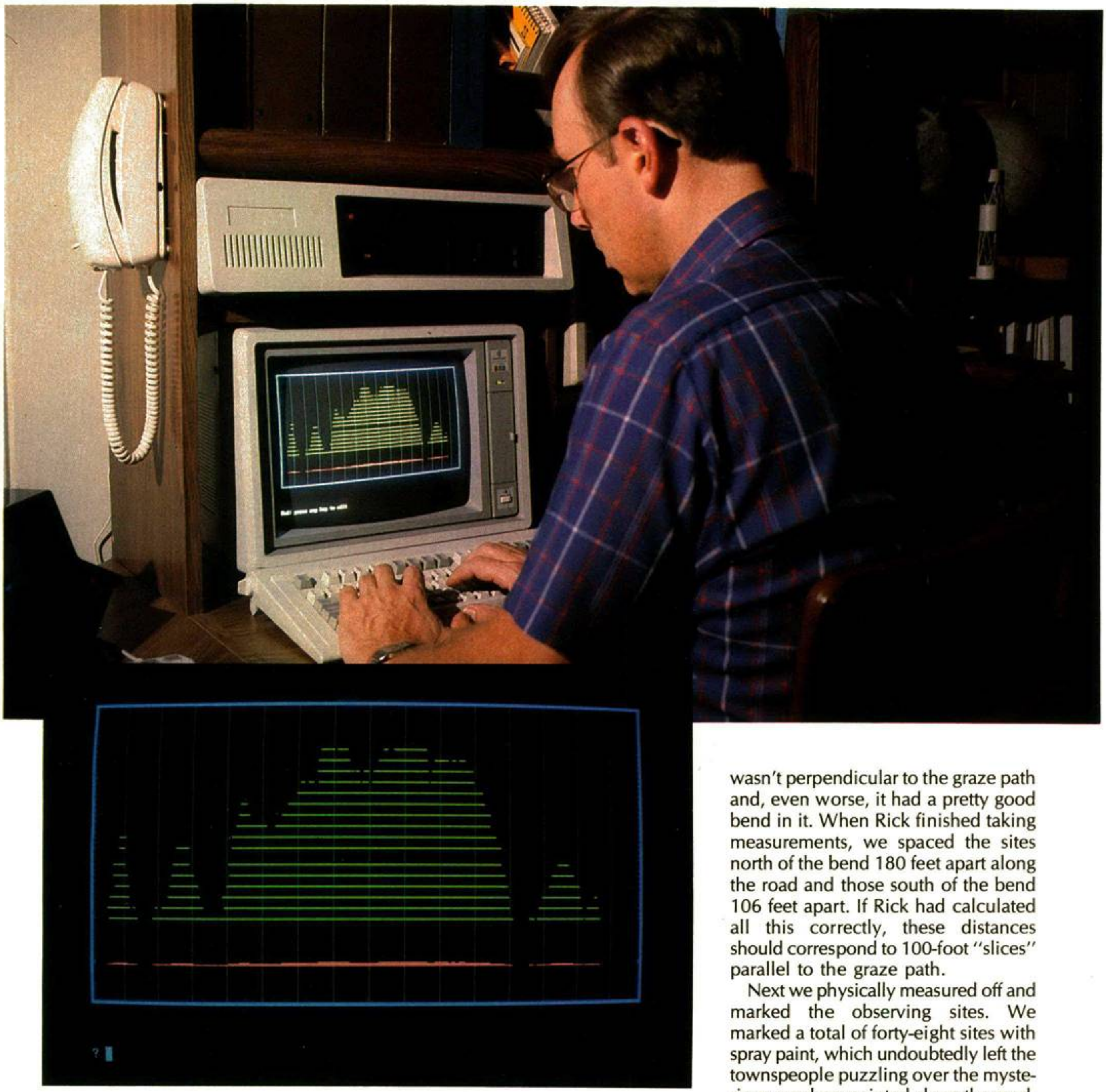
To select the location and individual observing sites for the El Nath occultation, we started with a table of coordinates for the predicted path supplied by IOTA and the *Index to Topographic and Other Map Coverage* available from the U.S. Geological Survey. The *Index* has enough detail to select the large-scale map (1:250,000) that covers the appropriate area. (Local U.S. Geological Survey maps are available from most map supply companies and many wilderness-outfitter shops.) We then plotted the predicted path on the large-scale map.

The three criteria for selecting a site are easy access by automobile, an easily identifiable landmark for reference, and low light pollution. The first condition dictates a road, preferably an infrequently traveled, straight, north-south one. The second criterion can be satisfied by a highway intersection, a bridge, or any other landmark you can accurately find both on the map and at the site. Because El Nath is bright and we were working with a gibbous Moon, the third condition was not important in our case.

We determined that the optimal location for viewing the El Nath occultation would be near the town of Tilden, Texas, roughly sixty miles south of San Antonio, at 4:09 CDT on October 12, 1987. The town (with a population of two hundred) lay directly on the predicted graze path and provided easy access for all the observers. Two weeks before the event we drove down to Tilden to make a preliminary survey.

Based on prior experience — this was the fourth occultation for members of the San Antonio group — our first priority was to coordinate our plans with the town sheriff. A twenty-car invasion at 3 a.m. arouses a lot of curiosity, to say the least! In the interest of science and our own hides, we wanted to avoid any confrontations. Sheriff Reeves (yes, he's related to Robert) was very congenial and supportive of our efforts.

Our next task was to determine where to place each observer. Our objective was to space sites at 100-foot intervals along a line perpendicular to the graze path defined by



THE MOON'S PROFILE is revealed as Ron Dawes (top) calls up a computer plot of the observations. A close-up look (above) shows the lunar limb features.

the IOTA coordinates.

The job of calculating the individual site locations fell to Rick Frankenberger. He first obtained the U.S.G.S. 7-1/2′ series map for Tilden (scale 1:24,000) and plotted the coordinates provided by IOTA.

Because the base line is derived from the average diameter of the Moon — and the Moon's polar diameter is smaller than the average diameter — we wanted the observing sites to start a quarter mile south of the reference line and continue south for another mile. If there had been a road perpendicular to the base line, we would have had it made by just measuring 100-foot intervals along it.

Unfortunately, no such road existed in Tilden, as our site survey team found out. Without a surveyor's transit or a calculator we wondered how we should place the sites. We managed to locate the two ends of the row of observing sites by using the map scale and a ruler with square corners. This is not a terribly critical measurement because normally you expect to have stations that extend outside the area of interest: at one end an observer will see a single, long disappearance and at the opposite end an observer will see a complete miss.

Our problem was that the road wasn't perpendicular to the graze path and, even worse, it had a pretty good bend in it. When Rick finished taking measurements, we spaced the sites north of the bend 180 feet apart along the road and those south of the bend 106 feet apart. If Rick had calculated all this correctly, these distances should correspond to 100-foot "slices" parallel to the graze path.

Next we physically measured off and marked the observing sites. We marked a total of forty-eight sites with spray paint, which undoubtedly left the townspeople puzzling over the mysterious numbers painted along the road.

The biggest source of error in positioning the observing sites is usually map error. The U.S. Geological Survey 1:24,000 maps are guaranteed to have no more than 10 percent of the major landmarks in error by more than 40 feet. You have no control over the map's errors in the location of landmarks, but you can reduce the effect of any errors by finding the end points for each row of observing sites and locating the individual sites by interpolating between the ends.

At the risk of greatly oversimplifying the entire process, Rick calculated the latitude and longitude of each site by measuring the distance of known points on the map from a known latitude and longitude as carefully as possible and interpolating the points in between.

Spectacular Graze Coming to North America in November

Your chance to participate in a grazing occultation expedition could come this autumn. In the early morning hours of November 30, a 57 percent-lit waning Moon will occult 1st-magnitude Regulus for observers throughout most of the United States and Canada. And for lucky observers on the northern and southern limits of the occultation track, a dramatic grazing occultation will be visible.

The southern graze path runs roughly from San Francisco, California, through southern Nevada, northern Arizona, central New Mexico, and Austin, Texas, to slightly south of Houston, Texas. Along this path observers will see Regulus graze the southern edge of the Moon. The Moon's southern limb is very rugged and will provide many separate occultation events as Regulus passes behind the lunar mountain peaks.

The northern graze path passes through Newfoundland, extreme eastern Quebec, and Labrador, Canada. Unfortunately, the occultation there occurs shortly after sunrise and thus will be considerably more difficult to observe.

In addition to providing details about the southern and northern limbs of the Moon, the November Regulus graze presents an opportunity to accurately measure the polar diameter of the Moon. By comparing observations made along the southern graze path with those made along the northern path, astronomers can deduce the Moon's polar diameter from careful measurements of the individual observers' locations on Earth.

The International Occultation Timing Association is looking for people to observe this important event. Anyone interested in organizing or participating in a Regulus graze expedition should contact either IOTA headquarters or the regional IOTA coordinators for the area. In the San Francisco area, contact James H. Van Nuland, 3509 Calico Avenue, San Jose, CA 95124. In the Phoenix area, contact Peter Manley, 1533 West 7th Street, Tempe, AZ 85281. And in the Austin area, contact Paul Maley, 15807 Brookvilla, Houston, TX 77059.

An Observational Success

The occultation expedition came off without a hitch. The sky was crystal clear, the temperature in the sixties, very little wind, and no dew. No one suffered any equipment failure. Eighteen observers made the trip, and each received a site assignment and instructions. With telescopes, radios, and recorders in tow, we drove off into the Texas darkness in breathless anticipation.

At 4 a.m. central daylight time (plus or minus a few minutes) we all tuned in WWV and started our tape recorders. At 4:08:30 the show began. Because the Moon was a 70 percent waning gibbous, we expected difficulties, with the star most likely disappearing behind a sunlit mountain peak. However, El Nath slowly drifted by the bright limb and shone brightly over the dark portion of the Moon for what seemed an interminably long time. Then, suddenly, catching most of us by surprise despite our anticipation, El Nath winked out. And almost as suddenly for many it "popped on" again. Over the next few minutes the star continued winking off and on as the Moon slowly slid by. As quickly as possible each observer spoke into the tape recorder with a "D" for "disappear" or "R" for "reappear." The star reappeared one last time and still we waited, just in case. It was over.

Everyone witnessed at least one disappearance/reappearance and some saw as many as six full events. Many of us were surprised that El Nath did not blink out instantaneously. During many of the individual events it faded out, or faded in, in steps. This was because El Nath is a multiple star system, and we were seeing each star occulted separately. In some cases the drop in brightness lasted over a second.

After a month of preparation the entire occultation lasted less than three minutes. We gathered after the event to turn in the observation tapes, compare notes, and to report any unusual aspects of the occultation. We departed from Tilden at around 6 a.m. tired but pleased with the night's events.

Almost Instant Results

Taking the observations made during a lunar occultation and converting, or "reducing," them into useful scientific data is normally a very time-consuming project. In the past, IOTA's Paul Maley has reduced the observations made by San Antonio observers, but this time Paul was busy and we had to do it ourselves. Fortunately Ron Dawes had done some astronomical computing on his home computer, so we brainstormed ways to use his PC to reduce the data.

What we came up with was synchronizing the PC's built-in clock to the WWV signals recorded on each tape. The data-reduction program records the computer's clock whenever a key is pressed to indicate that the star disappeared or reappeared. Once all the data is entered and stored, the program stacks all the observations together and coordinates them to a common time frame.

Ron started reducing our data on the Friday evening following the occultation and was finished early Saturday afternoon, with time out for a full night's sleep. In less than twelve working hours our observations were converted into a profile of a relatively unknown area of the Moon having a resolution equal to the spacing between the observers.

Charting the Unknown Moon

For those interested, the program was written in Microsoft QuickBASIC under MS-DOS 3.1 on an IBM PC/XT clone. No special features, other than the clock, are required.

The graph on page 73 is the combined result of our observations and the computerized data reduction. Each horizontal line represents the period during which El Nath was visible from a given observer's vantage point. The blank areas show when the Moon blocked the star's light and thus reveal the profile of the lunar limb. The scale is expanded 50 to 1 vertically and has a resolution of 200 feet vertically and roughly 3,000 feet horizontally. The distance across the graph is roughly 101 miles wide at the Moon. The flat profile line at the bottom of the graph represents a truer picture of the actual lunar relief.

The eighteen observers who participated in this expedition were very proud of their accomplishments. Only four of the observers had ever observed a grazing occultation before, so the "rookies" played a major role in the expedition's success.

Astronomy, for the most part, is a very personal endeavor. But this event shows that amateurs working as a group can make a significant contribution to science. Grazing occultation expeditions are challenging, fun, and scientifically rewarding. They are also something your astronomy group can do. Other areas of the Moon remain to be charted — reach for them. ☐

Robert Reeves, Ron Dawes, and Rick Frankenberger are dual members of the San Antonio and Randolph amateur groups. Reeves' most recent story for ASTRONOMY was "The Real Lives of Ten Top Astrophotographers" (March 1988). Dawes is Air Force captain specializing in computers. Frankenberger is a manager at the Peripherals Division of the Datapoint Corporation.

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Advertising Oops!

ASTRONOMY goofed on the photo in *Cheshire Instrument Company's* advertisement in the June '88 issue (p.75). See their ad on page 97 of this issue — with the photo as it should have been printed!

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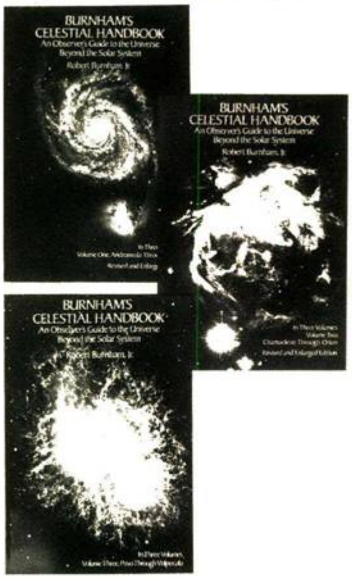
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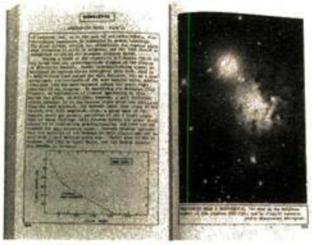

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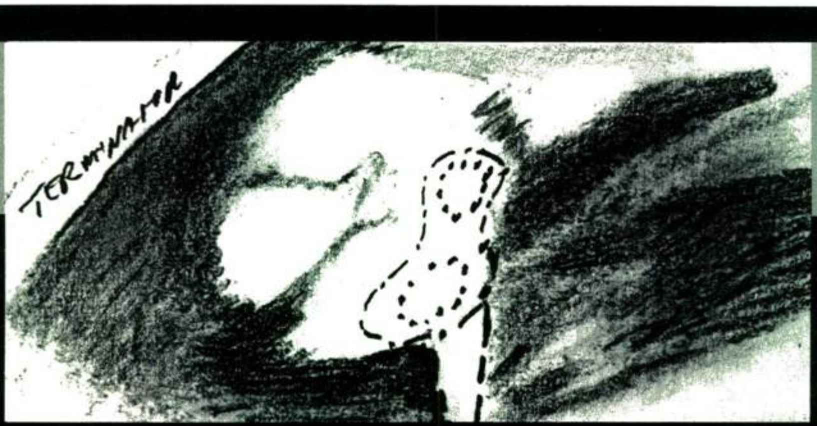
Forecast for Dust Storms on Mars

As Mars approaches perihelic opposition this fall, you may get the chance to watch the development of dramatic dust storms.

by Jeff Kanipe



PRECURSORS OF DUST STORMS often look like this bright cloud (dotted area) seen in the Hellas region on May 28, 1986.

LOOK FOR THE ERUPTION of Martian dust storms in certain regions of the planet, particularly Hellas-Noachis and Solis Lacus and Chryse.

Of all the planets that display atmospheric changes, only Mars has weather that can radically alter the appearance of its surface features. White clouds often hover over dark plains and basins, and bright hazes regularly edge the planet's limb or terminator regions. Most of this weather can be observed in 6- to 8-inch telescopes — especially as Mars approaches perihelic opposition, as it is now (September 28).

One of the most dramatic and easily observed climatological phenomena is Martian dust storms. A good telescope in the 2-inch or larger range, some patience, and clear, steady skies should enable you to watch an Oklahoma-type dust storm make over the surface of Mars this summer.

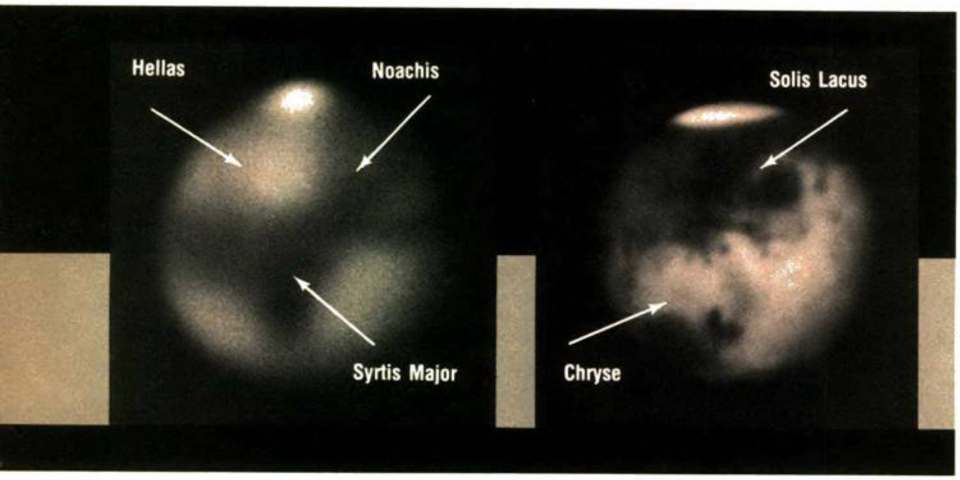
Martian dust storms can erupt at any time of the Martian year in either hemisphere, but historically the most spectacular storms occur around the time of the southern hemisphere's summer solstice, which this year is on September 11. As Mars nears the Sun, the increased warmth melts the southern polar cap, thereby reducing the amount of light reflected away from the planet. Mars' surface thus absorbs more heat, which in turn generates powerful convective wind currents that can exceed 180 miles per hour. These winds whip huge quantities of dust and sand two to three miles into the thin Martian atmosphere.

The time to look for emerging dust storms is now. Based on past Mars apparitions, many observers believe a major dust storm could occur anytime. If one occurs, the obscuring blanket of dust could rapidly obliterate surface features for weeks or even months.

Observers with small- to medium-sized telescopes can witness the fascinating development of Martian dust storms as well as monitor position and size changes in these storms from night to night. Naturally you want to be able to use some of the major Martian features as reference points, so the first thing you need is a good Mars map (like the map on page 64 of the March 1988 issue). Use the map at the telescope to familiarize yourself with the prominent features. Identifying these features requires magnifications in the 100x range for 2- to 3-inch telescopes and 200x or 300x for 6- to 8-inch telescopes. If the image seems steady enough, try higher magnifications, but cut back when Mars begins to look blurred and indistinct.

In their early stages, dust storms appear as discrete yellow clouds encroaching on darker regions of the planet. These yellow clouds can be fairly bright — though not as bright, say, as the polar cap — but they generally manifest themselves as an area of enhanced brightness within a region. A yellow filter (Wratten #12) helps brighten these clouds somewhat, and orange and red filters (Wratten #21 or #25) help delineate the boundaries of the clouds.

Small, yellow dust clouds often dissipate without growing much in size. However, given that these clouds often portend the development of major dust storms, monitoring the behavior of these little clouds pays off. You will know a major storm is in the making when a night or two later at the same location on the planet the small yellow cloud now covers a quarter to a half of the disk. Dark surface markings that were quite evident the week before now appear as vague, low-contrast blotches beneath a diffuse orangey haze. If the storm continues to grow, *within a week the dust could obscure* the entire planet, in which case an observer would see nothing but a bland, orange ball.



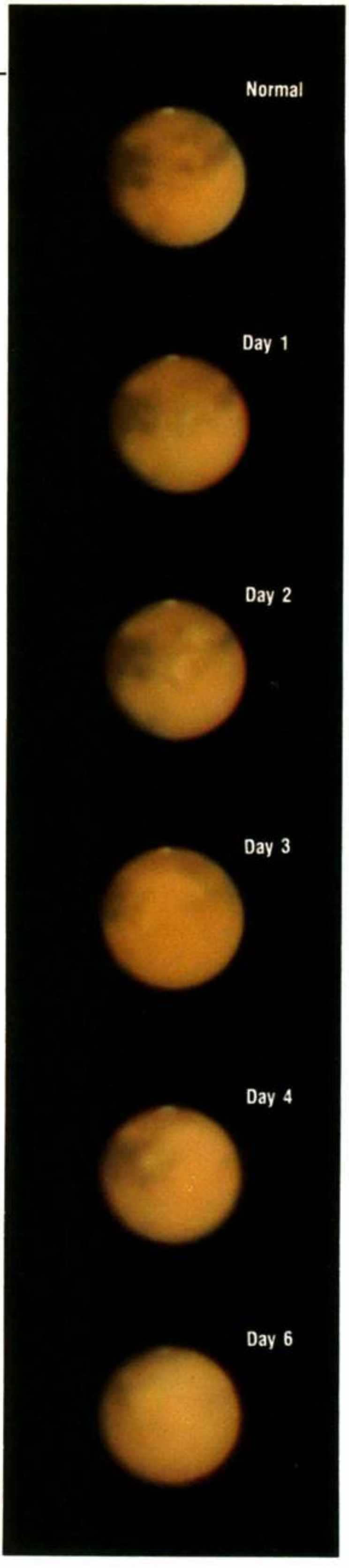
Most dust storms originate in the Hellas-Noachis region (which lies at Martian longitude 320° and south latitude 25°). Hellas is a large, bright, circular impact basin located in the southern hemisphere, south of Syrtis Major, a prominent, dark, wedge-shaped plain. Noachis is a plain adjacent to Hellas. Mars observer Charles F. Capen noted in a 1974 paper published in the journal *Icarus* that a small yellow cloud or haze was observed in the Hellas-Noachis region preceding the onset of major dust storms observed during the 1892, 1909, 1924, 1939, and 1956 apparitions. A yellow cloud was spotted just north of this region prior to the 1971 global dust storm.

The Hellas-Noachis region will be on or near the central meridian of Mars at about 10:30 EDT on August 13 and September 22. Remember that because Mars' day is 37 minutes longer than Earth's, a particular feature seen on the central meridian on one night takes an additional 37 minutes to again reach the central meridian the following night. Thus, if you see Hellas-Noachis on the central meridian at 10:30 p.m. on August 13, it will again be on the central meridian the following night at 11:07 p.m.

On the opposite side of the planet, dust storms are known to kick up out of the Solis Lacus region (longitude 90°, south latitude 20°) and Chryse Planitia (longitude 32°, north latitude 8°). Solis Lacus is a small, dark, comma-shaped feature easily seen when it stands out against the lighter surroundings of Solis Planum. Chryse is a bright plain lying northeast of Solis Lacus in mid-northern latitudes. The October 1973 global dust storm evolved out of the Solis Lacus region, and dust clouds were reported in the Chryse region during the 1982-84 apparitions.

Solis Lacus will be near the central meridian at 10:30 p.m. EDT on September 7; Chryse, also at 10:30 p.m. EDT, on August 5 and September 14.

Despite a tendency to occur *after* perihelion, dust storms are unpredictable, as is the extent of their coverage. Therefore the best way to see a dust-storm outbreak is by keeping a wary eye on the planet night after night, if possible. And even if a storm has already shrouded the planet in dust, looking for features appearing in "holes" in the dust cloud or for the first signs of clearing after the storm can be exciting. ☐



A GLOBAL DUST STORM begins innocently enough, as evident in this series of photos taken during the 1973 Martian apparition. This storm broke out in the Solis Lacus region and practically covered the globe six days later. Observers with telescopes can monitor the progress of storms like this one over successive nights.

Dark Skies for the Perseid Meteor Shower

Take advantage of this year's great viewing conditions to observe and photograph the Perseids at peak activity on August 12.

by Philip M. Bagnall

You're in for a great show on August 12. Under a dark sky you can witness one of the sky's most spectacular annual events, the Perseid meteor shower. This year it isn't just "any" Perseid shower, either, for two reasons. The radiant, the point from which the meteors appear to come, will be high in the sky during peak activity for North American viewers. Second, this year the Moon — an occasional "Perseid wrecker" — is New on the same day and will not interfere at all. Anyone under a clear sky away from cities will have a dark sky ideal for meteor watching.

The best time to watch the Perseid shower is early in the morning on August 12, when the shower peaks at about one bright meteor per minute. Lesser numbers of Perseids are visible for a number of days before and after the 12th.

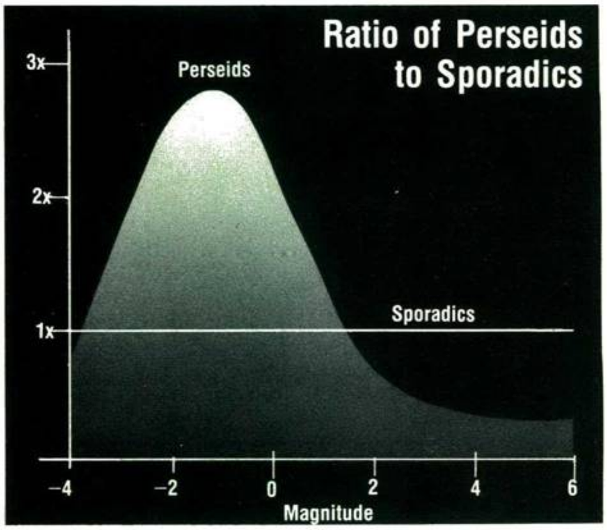
Under this year's ideal circumstances the Perseid shower will be an enjoyable event for backyard observers. It offers a chance to trek outside, sprawl out on a lounge chair, and look skyward for the year's best show.

If you want to become more involved, the Perseid shower offers the opportunity to do some real science by plotting observations or recording meteors photographically. Organizations like the American Meteor Society, the British Meteor Society, and the Association of Lunar and Planetary Observers utilize amateur observations of the Perseid shower in their studies. These organizations want to receive photographs and reports on the numbers and types of meteors observed. Whichever route you take, knowing something about the background of this remarkable event will let you appreciate seeing each streak of light just a little more.

The Past Perseids

The Perseids are the oldest known meteor shower. The earliest record of Perseid activity dates back to July 17, 36 A.D., when Chinese skywatchers noted that "more than one hundred meteors flew thither in the morning." The shower was observed in Europe as early as 811 A.D. and was very active in the eleventh century. Over the years the radiant, originally well within the boundary of Cassiopeia, slowly drifted toward Perseus, which gave the shower its name. Today the Perseids appear to come from a point near Eta Persei but within Cassiopeia.

The Perseids' rate of activity has ebbed and flowed over the past century. The British astronomer William F. Denning produced the first modern study of the Perseids after observing the shower between 1869 and 1898. Denning placed the average time of maximum activity on August 9/10 and observed an average of fifty meteors per hour. By 1911, however, the rate plummeted to only four meteors per hour and stayed at that level for several years. This suggested to Denning that the shower was dying out. It wasn't. To the delight of meteor observers the Perseids came alive in 1920, when observers viewed 196 meteors per hour. The following year astronomers witnessed an incredible 250 meteors per hour.

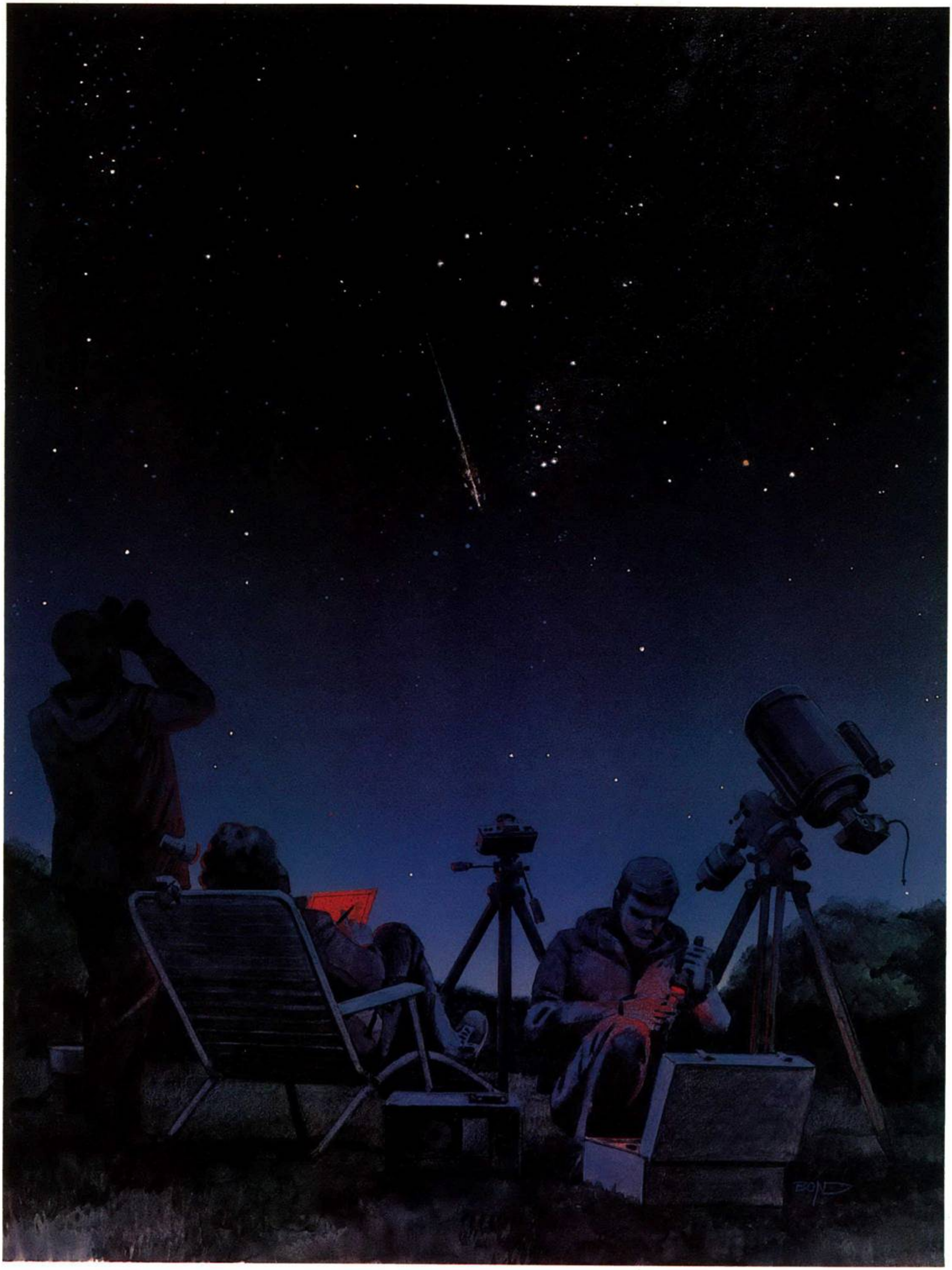


PERSEIDS ARE EASY TO SEE, even in slightly light-polluted skies. Compared with random background meteors, the shower produces nearly three times as many bright meteors.

Since the 1920s Perseid activity has remained high, averaging sixty-five meteors per hour. For several years, beginning in the 1970s, the rate increased substantially, culminating in 1980 with a display of two hundred meteors per hour. The rate has since declined to about sixty meteors per hour, but the shower's great activity around 1980 illuminated the mystery of a long-lost comet responsible for the Perseid shower.

Source of the Perseids

Comets are the parent bodies of meteor showers. In the deep freeze of the outer solar system, comets are inert snowballs made of frozen gases and dust. But as comets approach the Sun, they heat up and their ices turn into gases, which release dust previously trapped in the ice. In the process, comets leave substantial trails of dust,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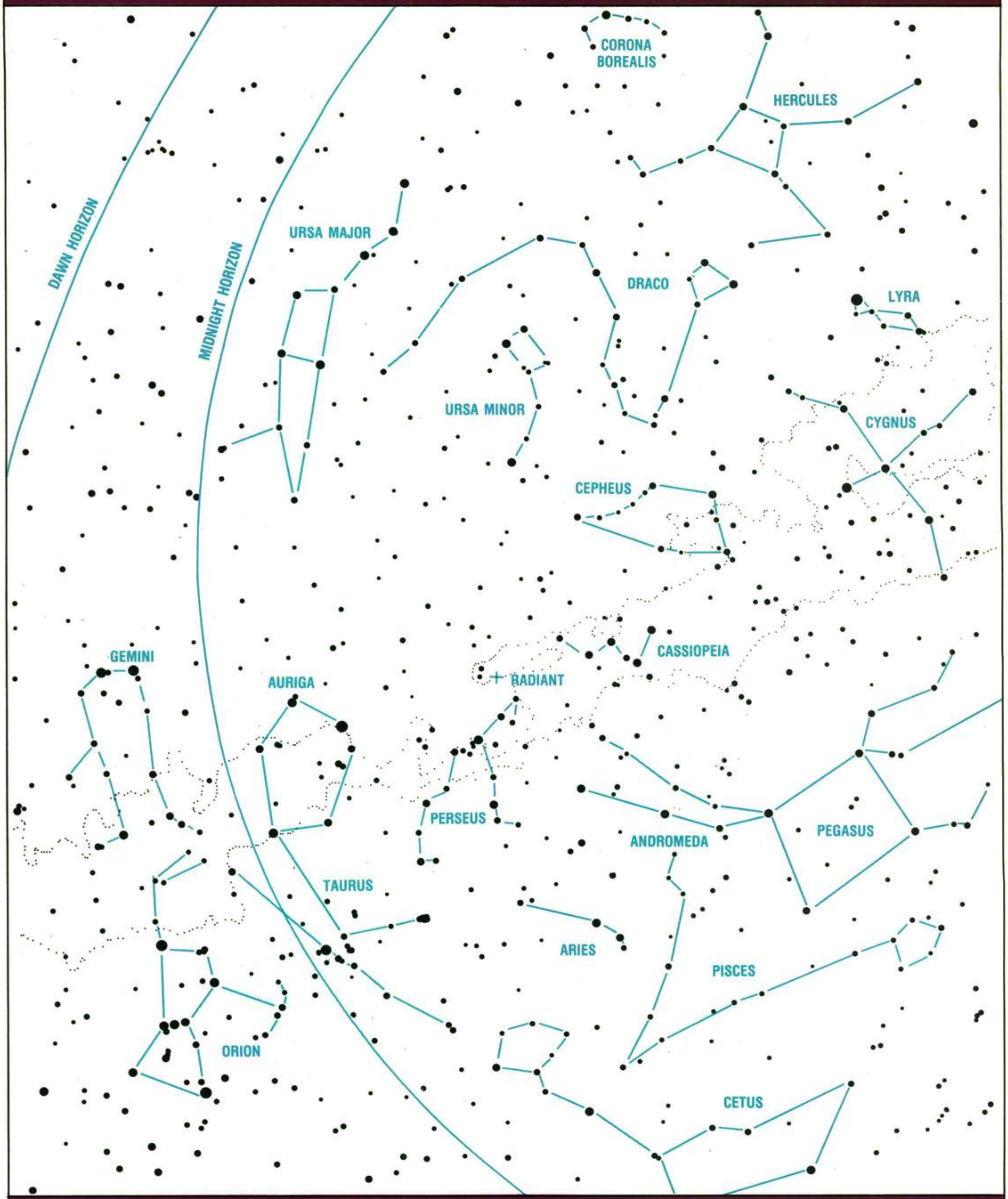
PLOT THE PERSEIDS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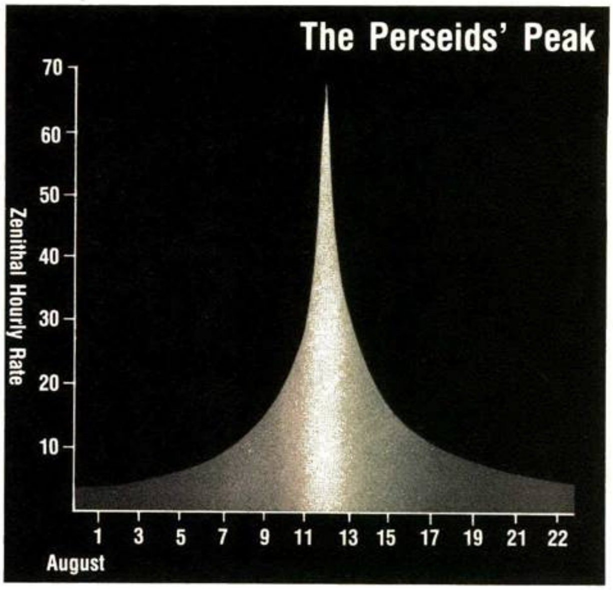
HERCULES
DAWN HORIZON
MIDNIGHT HORIZON
URSA MAJOR
DRACO
LYRA
URSA MINOR
CYGNUS
CEPHEUS
GEMINI
CASSIOPEIA
AURIGA
RADIANT
PERSEUS
PEGASUS
ANDROMEDA
TAURUS
ARIES
PISCES
ORION
CETUS

PHOTOCOPY THIS MAP and plot Perseid meteors you see throughout the night of August 12. The Perseid radiant is well above the horizon at midnight for observers at 40° north latitude and nearly straight overhead by dawn. Perseid meteors will appear to streak across the sky in all directions. As you plot meteors, count them by the hour and record your results.



PEAKING ON AUGUST 12, Perseid meteors are visible from the end of July to the end of August.

called meteor streams, along their orbits. When Earth crosses one of these meteor streams, dust particles fall into Earth's atmosphere and vaporize, causing a meteor shower.

The first person to connect comets with meteor showers was the Italian astronomer Giovanni Schiaparelli. In 1867 Schiaparelli noticed that the orbit of the Perseid shower closely matched that of a bright comet that had been discovered in 1862, Comet Swift-Tuttle 1862 III. Because the orbits matched, Schiaparelli knew that Swift-Tuttle was the source of the Perseid meteor stream. He also calculated the orbital period of Swift-Tuttle at 120 years. But Swift-Tuttle did not reappear around 1980, 120 years after its discovery. The increased Perseid activity around 1980, however, did lend support to the connection between the Perseids and the lost comet.

Schiaparelli knew the Perseids had been observed as early as 36 A.D., but the comet's past remained elusive. No previous observations of comets seemed to match Swift-Tuttle's 120-year period. However, long after Schiaparelli's death, solar system researchers reinvestigated the mystery. Brian G. Marsden, cometary science expert at the Harvard-Smithsonian Center for Astrophysics, analyzed all the available data to trace the history of Swift-Tuttle.

Marsden found that before its 1862 apparition Swift-Tuttle had passed close to Saturn and Jupiter, which increased the comet's orbital period by about five-and-a-half years. With this in mind, Marsden next looked for past comets that might match the changing orbit of Swift-Tuttle. A possible match came from observations made by a Jesuit missionary describing a 3rd-magnitude comet in July 1737. From this Marsden calculated previous appearances in March 1610, December 1479, and September 1348. Marsden calculated that Swift-Tuttle would be invisible from Earth during the 1610 and 1479 encounters. But a search in Japanese annals showed a match in 1348: Swift-Tuttle and the comet recorded by the missionary could be the same object. If this is true, Marsden predicts a reappearance of Comet Swift-Tuttle sometime around November 1992.

Observing the Perseids

The golden rule of meteor observing is to be comfortable. Temperatures fall as the night progresses, so protective clothing may be required. A lawn chair is ideal for comfort and a mug of coffee or soup will help keep you awake and warm.

Optical aid is not necessary for observing the Perseid shower, but a pair of binoculars sometimes comes in handy. Some meteor trains remain visible in binoculars for several minutes. If you follow a train in binoculars, time how long it remains visible and note any changes you see in its shape.

Generally you can see Perseid meteors between July 23 and August 20, though a few stragglers may be visible for one or two days before or after these dates. This year's shower peaks on August 12.

The number of meteors you see depends on the time and sky conditions. Under a perfectly dark sky with the radiant overhead, you might theoretically see as many as sixty-eight meteors per hour. This number is called the shower's Zenithal Hourly Rate. Such an ideal situation rarely occurs in reality. You can get a better idea of the rate you're likely to see by using this formula:

$$EHR = ZHR \sin A,$$

which states that the Expected Hourly Rate is equal to the ZHR, multiplied by the sine of the angle of elevation of the radiant in degrees. The higher the radiant in the sky and the darker the sky, the more meteors you'll see.

The Perseid radiant lies at right ascension 3h05m, declination +58° (2000 coordinates) on the 12th. With each passing day the radiant appears to drift east +1.35° in right ascension and north 0.12° in declination. Some observers have reported seeing a second radiant at approximately 2h48m R.A. and +54° dec. In 1931 a third radiant was reported at about 2h43m R.A., +54.4° dec., near the star Tau Persei. Multiple radiants sometimes indicate a meteor stream split into several components, but so far reliable data on the secondary radiants are sparse and no conclusions can be drawn.

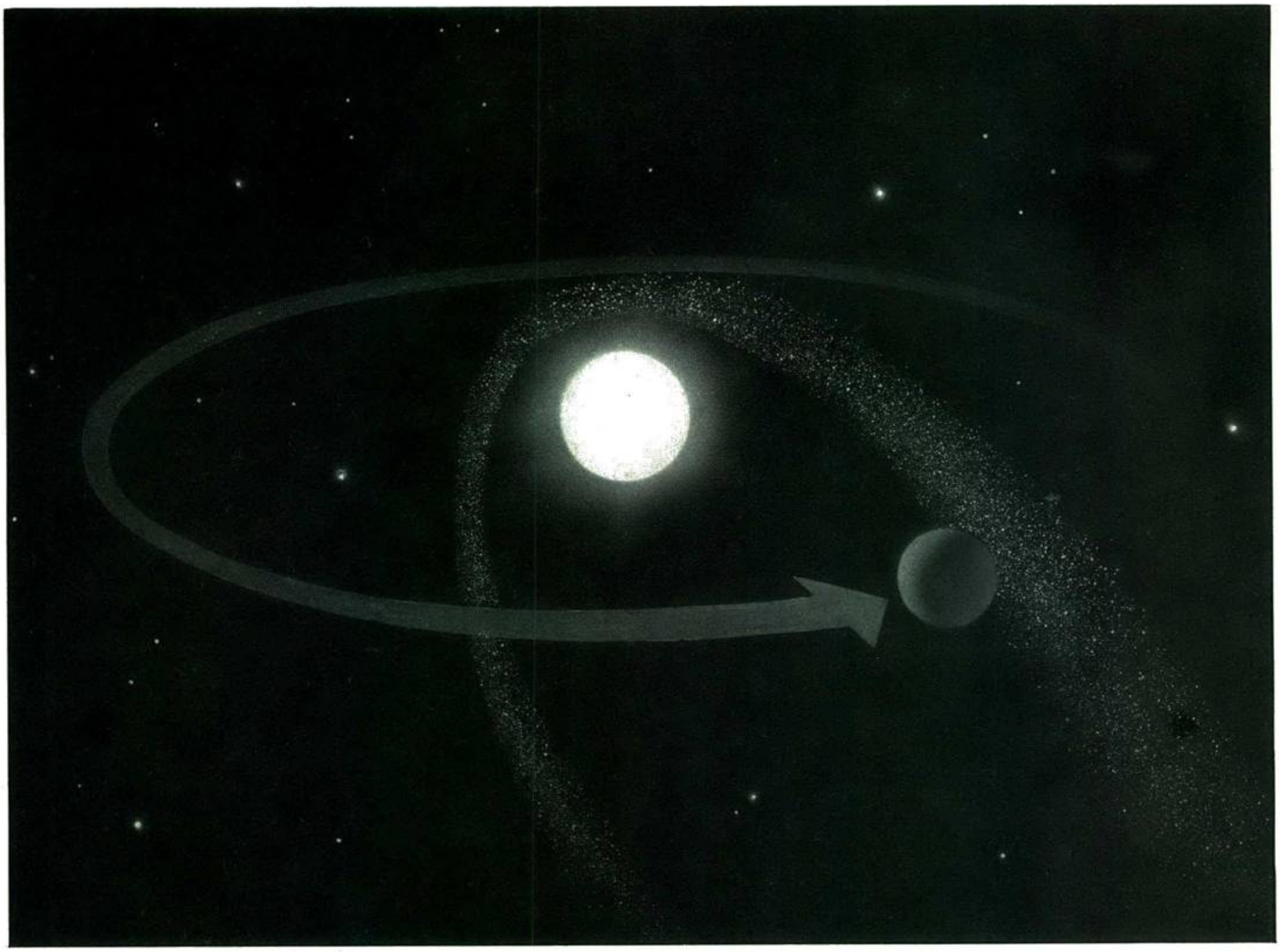
Both the radiant and its drift are optical illusions. Meteors travel in parallel trajectories and only appear to radiate from a point because of their great distance. The illusion is analogous to the way automobiles on a freeway appear to converge to a point on the horizon. Radiant drift is simply due to the Earth's entering, passing through, and exiting the meteor stream.

In addition to just looking at the Perseids, there are several other ways to experience the shower. The simplest is to keep a running count of the meteors you see over a period of an hour. This means writing down the time each meteor appears, the meteor's magnitude (an accuracy of one magnitude is acceptable), and its duration and color. Extremely bright meteors often leave a "train," a faint trail visible for a few seconds. If you see one, be sure to describe its appearance. It will probably appear like a thin, faint streak of gray light.

You can also use the map on page 80 to sketch the paths of meteors you see. Do this by making a mental note about the meteor's trajectory relative to bright stars near the beginning and end of the meteor's trail. Then, as quickly as possible, transfer the position to the map. Remember that if traced backward, all Perseids will intersect near the radiant. If you see a meteor that doesn't, it is probably a sporadic meteor that doesn't belong to the shower.

Photographing the Perseids

If you have a 35mm camera, you might want to photograph the Perseid shower. You will need a camera



WHEN STREAMS OF PARTICLES left in the wake of comets cross Earth's orbit, we see a meteor shower.

capable of making time exposures, a fast lens (preferably f/2 or faster), fast film (preferably ISO 400 or higher), a tripod, and a locking cable release.

Mount the camera on the tripod and point it toward the same area of sky you are watching. Set the camera's focus at infinity and open the aperture wide. Using the cable release, lock the shutter open. The exposure time depends primarily on sky conditions. In dark skies you could probably leave the shutter open for as long as an hour, but in the city you may be limited to about five minutes before the film begins to fog. When you see a meteor flash through the part of sky you are photographing, stop the exposure.

If you want a more complex photographic project, get together with a friend and try dual-camera photography. This technique allows you to calculate the position of a meteor in Earth's atmosphere if both of you record the same meteor from different locations. Set up the telescopes a mile apart. Use two piggybacked wide-angle lenses and photograph the same area of sky. (You may want to keep in contact with each other using a pair of walkie-talkies.) If you each record the same meteor, you can calculate the meteor's height based on the known distance between the cameras. For more information on this technique, contact one of the organizations listed below.

If you're pleased with your notes, sketches, or photographs, consider sending copies to any or all of three associations. In this way you'll be contributing to the historical record of what astronomers know about the Perseid shower. For more information, send a stamped, self-addressed envelope to: Association of Lunar and Planetary Observers, P.O. Box 16131, San Francisco, CA 94166; the American Meteor Society, Department of Physics and Astronomy, State University of New York, Geneseo, NY 14454; or the British Meteor Society, 26 Adrian Street, Dover, Kent CT17 9AT England.

This year the Perseids are at their best, showering the sky with a meteor per minute. Whether you simply lie under the stars and soak up the sky or photograph the shower for scientific results, prepare early and catch up on sleep. If you do, you'll likely remember 1988 as a great year for meteors. ☐

Philip M. Bagnall, an amateur astronomer from Wallsend, England, is currently director of the British Meteor Society International Micrometeorite Research Network. His last article for ASTRONOMY was "Observe the Naked-Eye Sky Glows" (June 1988).

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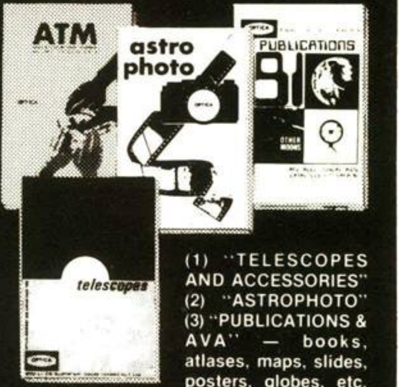

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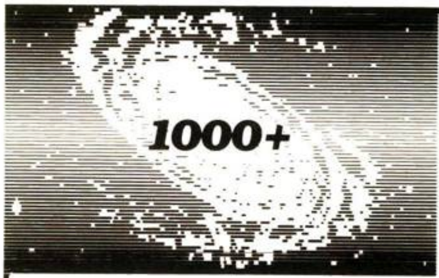

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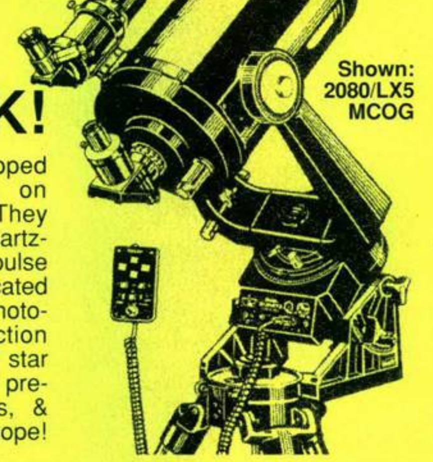

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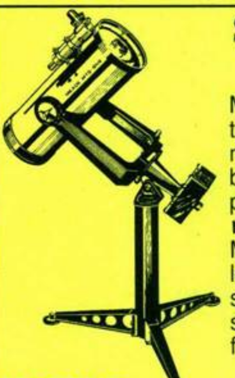

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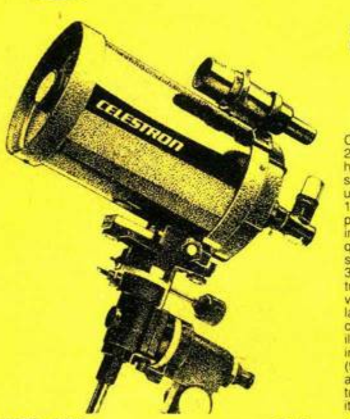

Super Polaris C8

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SP-C8 .... (List: $1,620) **.......... $ 917.95**
SP-C8 StarBright (List: $1,800) **.......... $1,037.95**

FREE FREIGHT! (UPS Ground) for the SP-C8's shown above

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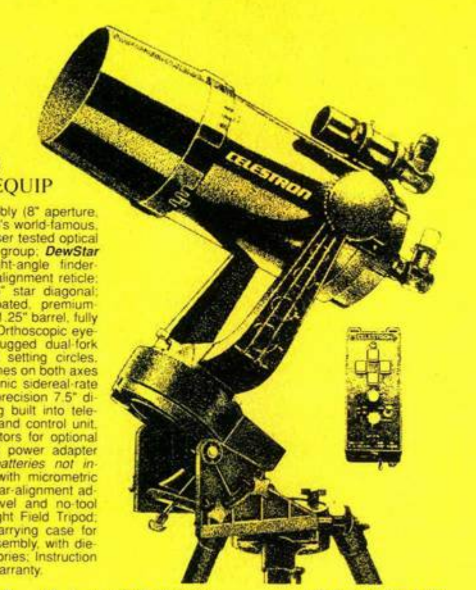

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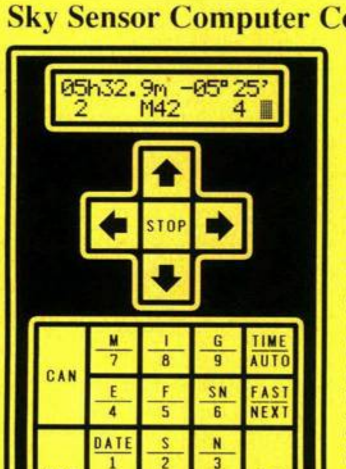

The ***Super Polaris*** German-equatorial mount is one of the most useful general-purpose astronomical mounts for amateur astronomers and astrophotographers. One aspect of its "application-flexibility" is the variety of motor-drives made for it. Very sophisticated single-axis, dual-axis and dual-axis-computer (***SkySensor***) quartz-regulated, micro-electronic pulse-motor drives are available for the ***Super Polaris***, and are easily attached or dismounted by means of a few screws. Of these three drives, the ***SkySensor*** is the most advanced and interesting: it is actually a very powerful ***telescope-controlling computer***, with an internally-stored catalog of 762 astronomical objects. The computer itself has 22 command/control keys (14 of which are dual-function), as well as a 32-character, alphanumeric liquid-crystal display. Capable of slewing the mount at 15 arcmin/sec/axis, ***Skysensor's*** dual-axis motors can point your telescope at any of the internally-cataloged objects, or at any other object whose coordinates you input. In addition, ***SkySensor*** provides ***complete manual control*** of the telescope's motions, at both the slew and "photographic guiding" speed rates, by means of its manual-motion-control keys. Finally, for those who are "computer-literate" (not for novices), ***SkySensor*** is also equipped with an RS-232-C serial communication port, by means of which a personal computer may be electronically "piggybacked" onto ***SkySensor***, to take control of it. The ***SkySensor*** instruction manual covers the PC computer command structure for ***SkySensor***, and even includes some sample BASIC source code. Complete kit includes ***SkySensor***, stepper-motors, drive gearing & clutches, bracketing, tools, cables, instructions & hardcopy of the stored object catalog *(12VDC power supply **not** included)*.

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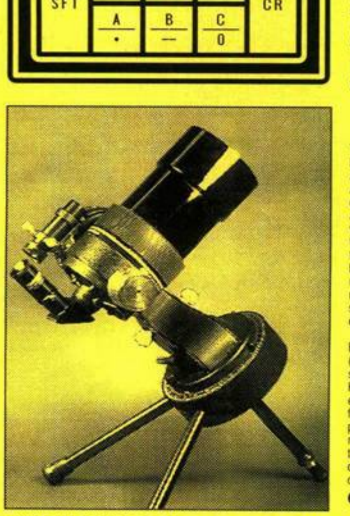

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C90 Astro (List: $1,300.00) $799.95

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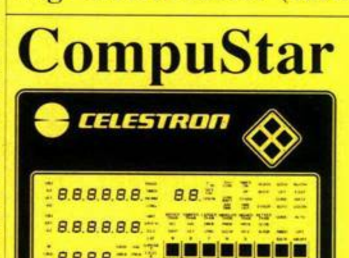

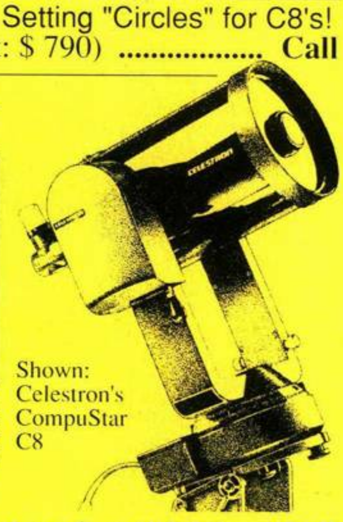

Shown: Celestron's CompuStar C8

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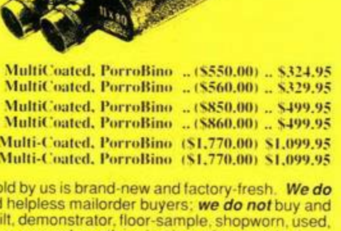

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ASHEN LIGHT ON VENUS

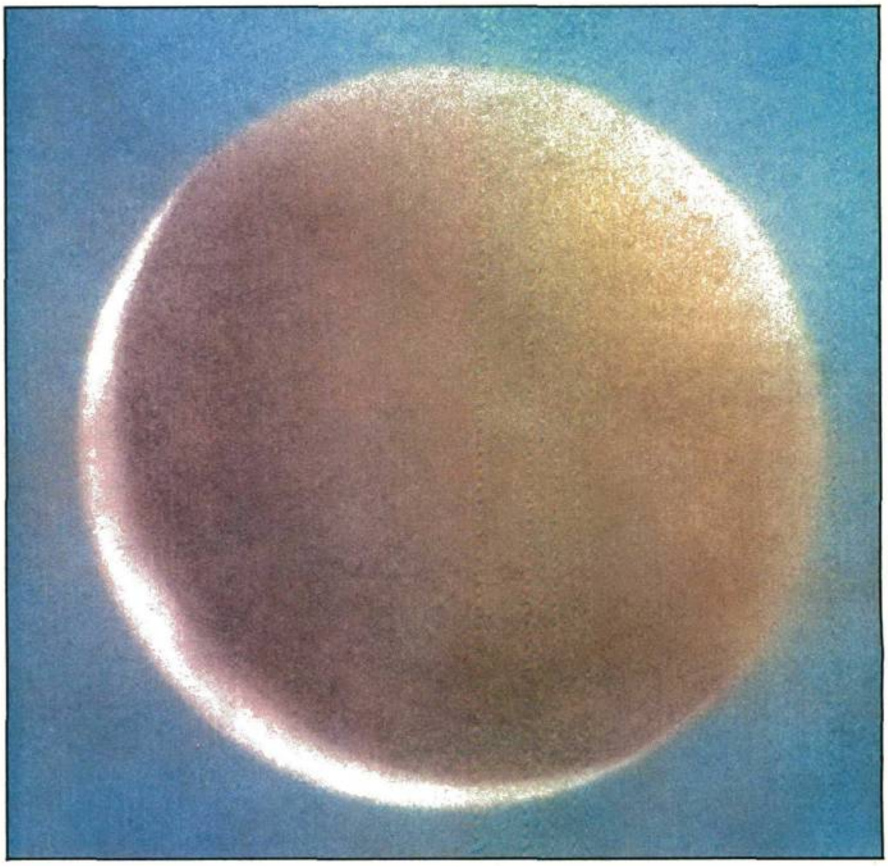
Since 1643 when a faint glow on the dark side of Venus was first observed by Giovanni Riccioli, other observers have occasionally reported seeing this glow. In his 1715 book *Astro-Theology* William Derham wrote: "This sphaericity [*sic*], or rotundity, is manifest in our Moon, yea, and in Venus too; in whose greatest falcations the dark part of their globes may be perceived, exhibiting themselves under the appearance of a dull and rusty colour."

Called ashen light, the glow on the dark side of Venus is visible when the planet is a crescent. As discussed by Derham, ashen light is reminiscent of earthshine — faint light reflected by Earth onto the Moon's unlit surface.

There's only one problem with the ashen light: its cause is not known. In the past, phosphorescent oceans, rotting vegetation, agricultural burning, artificial illumination, and a self-luminous atmosphere were all suggested as causes. Perhaps the most reasonable modern explanation is that ashen light is caused by the bombardment of atoms and molecules in Venus' atmosphere by charged particles from the Sun. In other words, it may be an auroralike phenomenon.

Some observers specialize in looking for the ashen light. Richard Baum of Chester, England, has been observing the phenomenon for over thirty-five years. Baum describes the ashen light as a "glow variously described as coppery, deep purple, olive, or even rusty brown. Often the glow is uniform, but occasionally it is patchy. One or two observers have seen a mottled ashen light, as I did in 1953. Happily that observation was confirmed by Mr. H. B. Heath, then director of the British Astronomical Association's Saturn Section, who happened to be observing Venus at the same time over two hundred miles away."

Venus is now visible in the morning sky as a brilliant crescent-shaped object spanning nearly 30". The planet is slowly decreasing in size and moving toward full phase, and the next few months are a good time for trying to spot this mysterious phenomenon. The Association of Lunar and Planetary Observers is currently managing a program for ashen light observers. (See Amateur News, July 1988). For more information on ALPO's program, write to Julius Benton, Jr., ALPO Venus Section, Associates in Astronomy, 305 Surrey Road, Savannah, GA 31410.



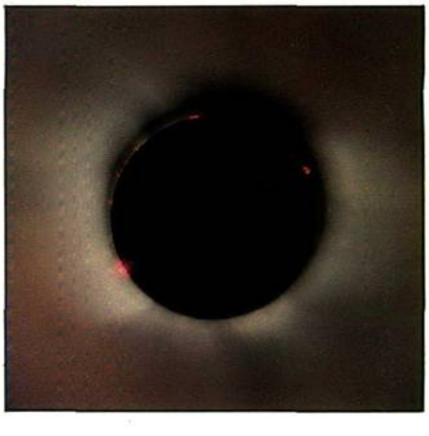
ASHEN LIGHT ON VENUS appears as a subtle copper-colored shading on the planet's dark side. English observer Richard Baum made this sketch of the rare phenomenon in 1953. The cause of ashen light is unknown.

MORE VIEWS OF THE SOLAR ECLIPSE

Last month's Reader Reports featured the first descriptions and photographs of the solar eclipse in the south Pacific on March 18, 1988. Since then we've received more reports and photographs of the eclipse.

The line of totality extended from a point in the Indian Ocean west of Indonesia to a point in the Pacific south of Alaska. Thousands of observers witnessed between two and four minutes of totality and two magnificent prominences arcing from the solar limb.

The large and active prominences delighted everyone. Veteran eclipse chaser Jacques Guertin, who viewed the eclipse from Borneo, described them as "a heart-shaped loop surrounded by a matching coronal loop. The other appeared like a mushroom with sharp protuberances." Richard H. Rosichan, viewing from the Philippines, was astounded by the corona. Rosichan explained that "second contact was visible through thin



PROMINENCES AND CORONA in March 18's solar eclipse were photographed by Ernest W. Piini of San Jose, California.

haze, and while the inner corona and prominences were clear, there was no outer corona. Then suddenly the clouds moved away and the outer corona sprang into view. It was as if two wide, irregularly shaped white brushes shot away from the Sun. That elicited gasps and whoops even louder than the ones I'd heard before."

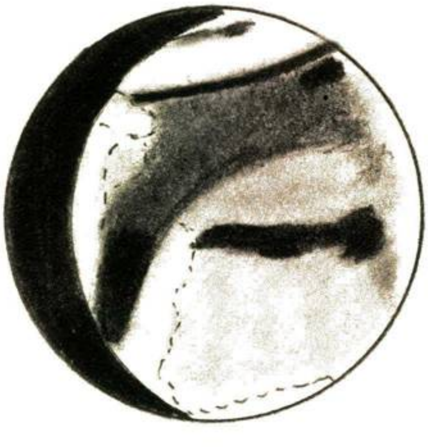
From the cruise ship *Golden Odyssey* in the Celebes Sea meteorologist Jay Anderson watched the entire eclipse after helping the ship's captain maneuver the *Odyssey* to avoid a threatening storm. "For those watching the eclipse," wrote Anderson, "the corona was the incredible spectacle, with multiple helmut plumes radiating above and below the Sun in a brilliant display. Those watching with telescopes marveled at a great looping prominence off of the top limb. For those with the foresight to bring a spectroscope or a diffraction grating, the flash spectrum was etched in memory.

"The presence of many noneclipse chasers added joy to the spectacle, bringing a chorus of cries and shouts as totality began," Anderson said. "As always on eclipse trips the Moon's shadow was gone too soon, and though the reappearance of a diamond ring received a cheer, a universal feeling of loss came when the Sun returned to the sky."

MARS OBSERVED AS IT SWELLS IN SIZE

During spring and early summer 1988 the disk of Mars grew enough that observers began paying attention to it. In April and May the Red Planet moved slowly through Capricornus and grew from 7" to 10" in diameter. Although this was less than half the size Mars will be at this September's opposition, last spring Mars was large enough to show surface features to telescopic observers.

Jeff Beish and Don Parker, Mars Recorders for the Association of Lunar and Planetary Observers, report normal activity on Mars so far. "The small number of white cloud features that have been seen," they said, "occurred over Phoenicis Lacus, Ophir, Chryse, and Tharsis. The South Polar Region has been unusually clear. Occasionally dull polar hazes and clouds have been observed forming along the western edge of the South Polar Cap. These are visible during the Martian morning and dissipate during the Martian afternoon.



SURFACE DETAIL ON MARS became visible in May when the planet grew to 10" in diameter. Donald C. Parker's composite sketch shows the view of Mars in a 16-inch scope at 485x and 730x.

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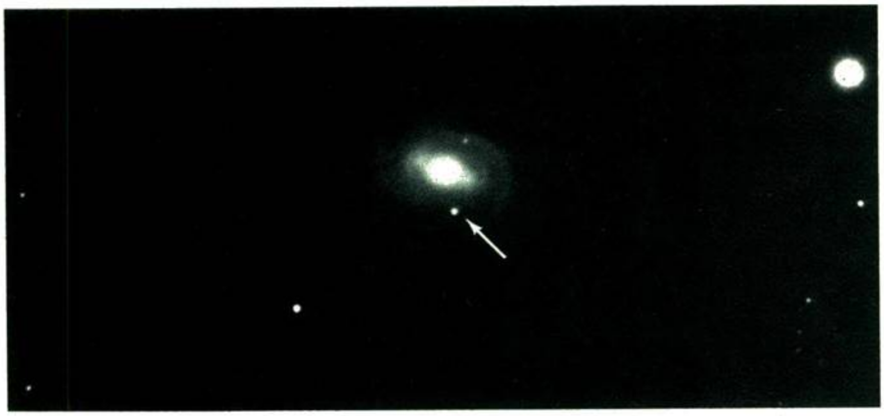
"In the eastern Hellas region we observed a dull yellow spot flanked by a bright white cloud near the South Polar Region. Dull yellow haze covered the eastern Sabaeus Sinus and Noachis regions. From these observations it appears that a minor dust storm was occurring during the first few days of May."



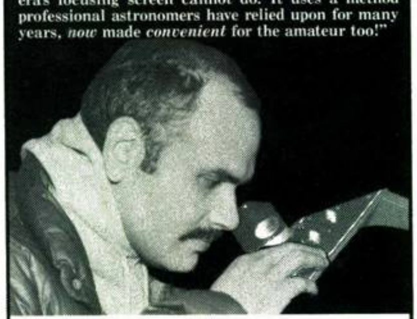
OUTSHINING ALL OTHER STARS in its home galaxy, a 14th-magnitude supernova (arrow) in galaxy M58 was faintly visible last spring. Kim Zussman photographed the object on April 10, 1988, with an 11-inch SCT.

SUPERNOVA OBSERVED IN GALAXY M58

This spring observers equipped with medium- or large-sized telescopes had the chance to see a supernova in the bright galaxy M58 in Virgo. The object was discovered by Kaoru Ikeya of Shizuoka, Japan, on January 18, 1988. Ikeya spotted an out-of-place 14th-magnitude star 40" south of M58's center. He checked to see if a star existed at that spot, found that none did, and reported the supernova to an astronomer at Tokyo Astronomical Observatory. The object was independently discovered by Robert O. Evans of Hazelbrook, New South Wales. Another Japanese observer, Shingo Horiguchi, later discovered that he had photographed the object on January 16.

Designated supernova 1988A, the object faded slowly after its discovery but remained bright enough to be observed and photographed by many amateur astronomers. On January 22, James Bryan of Georgetown, Texas, estimated the supernova's magnitude to be 13.9. On February 14, Dana Patchick observed the supernova from the Mojave Desert in California and estimated its brightness at magnitude 14.9. By late February the magnitude dropped below 15, which made spotting the supernova difficult for those without 16-inch or larger scopes.

Soon after the discovery of supernova 1988A, astronomers studied the object and determined it was probably a Type II supernova. Type II supernovae occur when a supergiant star of 8 solar masses or more expends its fuel, collapses, and explodes. Type II supernovae occur in the spiral arms of galaxies like M58. — *David J. Eicher* ☐



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WANTED — Halley's Comet commemoratives. For an offer send descriptions of items to Doug Smith, 385 Allison Road, Murfreesboro, TN 37130.

WANTED — Sturdy photographic tripod with three-way panhead to use with binoculars. Contact Bruce Smith, 3609 15th Avenue South, Minneapolis, MN 55407. Phone (612) 722-5034.

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WANTED — 3D postcards with space themes or information on where I can purchase them. Also want Questar eyepieces in excellent condition. Please send any information on these items to David Swinehart, 14738 27th Avenue NE, Seattle, WA 98155.

WANTED — High school student desires correspondence with amateur astronomers worldwide. I'm interested in astronomy (C8, especially astrophotography) and computers (A2000). Can write in English or German. Contact Alexander Jaehne, Wingertstr. 94, 6457 Maintal 1, West Germany.

WANTED — Pakistani student would like to correspond with amateur and professional astronomers all over the world. Would be pleased to join some international amateur astronomers association or club. Contact S. Zakiullah Hussaini, 1-J-45/4, Nazimabad No. 1, Karachi 18, Pakistan.

WANTED — Inexpensive telescope accessories (1-1/4" eyepieces, filters, etc.). Impoverished graduate student victimized by theft of all such items. 10" Cassegrain left blind until replaced. Any response greatly appreciated. Contact Douglas Hudgins, Box 173 Baker Laboratory, Cornell University, Ithaca, NY 14853.

WANTED — Accutrack automatic star tracking system for Accutrack drive corrector. Contact Joe Fedeli, 3291 Holme Avenue, Philadelphia, PA 19114. Phone (215) 443-1551.

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WANTED — Regular correspondence with anyone interested in astronomy anywhere in the world. Contact Michael D. Seekings, Oaktree Observatory, "The Golden Ball," Wisbech Road, March, Cambs., England PE15 0BA.

WANTED — French boy of nineteen would like to correspond with young people of the same age interested in astronomy, music, etc. Contact Xavier Schmaltz, 17 Allee de la Causette, 59650 Villeneuve d'Asq, France.

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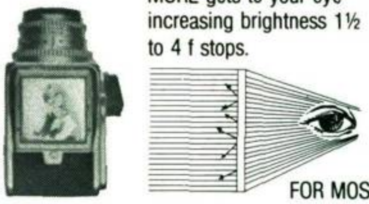

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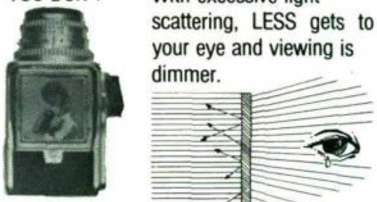

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BE PREPARED FOR SNAP DECISIONS

I learned my lesson the hard way when in my haste to try out a new nebular filter I decided to use a site I wasn't too familiar with. I had just finished setting up my equipment and was studying my star atlas when a truck burst in upon my solitude.

I don't think Horace Dodge ever intended his product to be so menacing. But menacing it was that night in the Tennessee woods. The truck came from nowhere and roared up to my site.

As dust clouds billowed across the headlight beams, I watched the doors on either side of the truck open like wings of some giant primordial bat. Two men jumped from the truck and came toward me. Their faces were masks of black, and they seemed seven feet tall with shoulders half as wide.

"What'cha think you're doin' here, fella?" one of them barked. "This here's private property."

Away from the cities of Tennessee, back in the "hollers," there are still plenty of folks who shoot first and ask questions later. Knowing mountain folk have a knack for seeing through a lie in half a wink, I decided to tell them the truth.

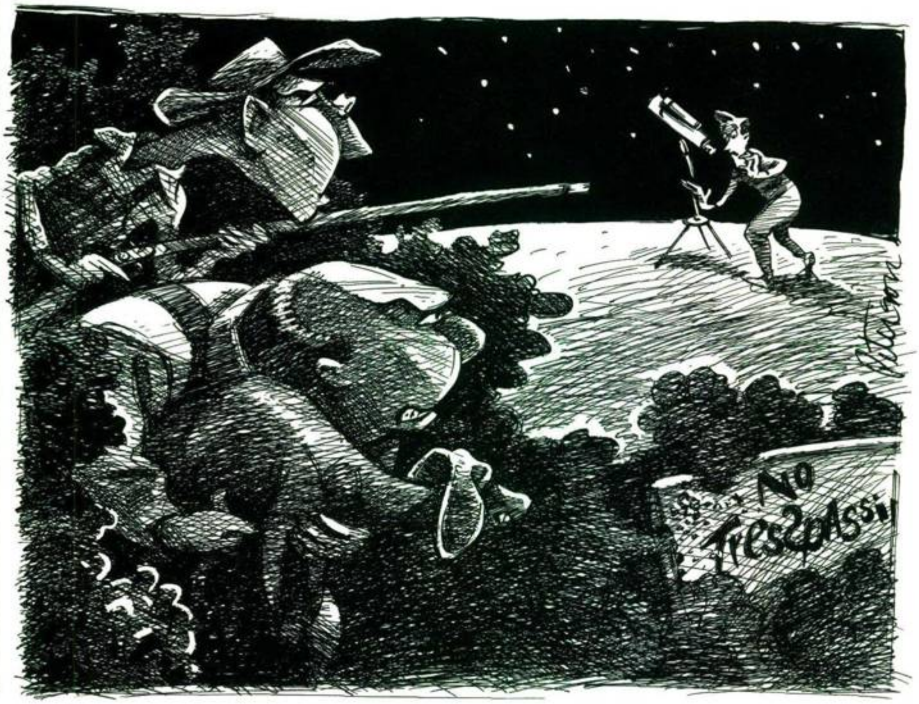
I arrived home late from work that afternoon and discovered that my new nebular filter had arrived, I explained quickly. I was anxious to try it out, but there wasn't enough time to go to my usual observing spot fifty miles east of Nashville. Besides, this filter was supposed to cut through city lights, so I loaded my cases in the van and took off north about fifteen miles.

Darkness was descending rapidly. I turned down a country road where I spotted a level clearing. In the center of the clearing were the remains of a house foundation, long abandoned. The only sign of civilization was a solitary light from a house two miles across the valley.

The men then explained that they lived in the house I had seen across the valley. The place I had set up at was their old homestead, and they still owned the property. I assured them I meant no harm and suggested that they bring their family over to have a look at the stars.

I was lucky that night. They turned out to be warm, friendly people. But it could have been otherwise. I learned a frightening lesson. From then on I would know where I was going before I set out and always obtain permission before setting up my equipment.

Besides being potentially dangerous, lack of preparation can also have disappointing results, as my friend Mike learned after he and I made a snap decision to drive 250 miles from Nashville to Roan Mountain in east Tennessee to observe Halley's Comet. The night was crystal clear, and we hoped the elevation on the mountaintop would offer terrific possibilities for piggyback photographs.



We didn't arrive on top of the mountain until about an hour before sunrise.

Roan Mountain was swathed in snow and ice; with the wind-chill factor the temperature felt −30 F. Carrying our equipment through the snow from the cars was exhausting. Adjusting the telescopes and camera with bare hands against cold steel was agony.

We didn't learn the awful truth until we were almost finished setting up our equipment: Mike had forgotten his camera lens! I was able to get three shots of Halley; Mike was devastated.

The lesson Mike learned was twofold: Snap decisions often result in chaos, but because you *will* make snap decisions from time to time, always keep your telescope and accessories ready to roll.

I keep all my accessories in aluminum suitcase-type cases. These cases, along with my telescope tripod, wedge, dew cap, binoculars, and charts are kept in one location in my home. Everything is always ready to go: I can load my van and leave in a flash.

The trick is to learn from your goofs and take action to prevent mistakes from happening again. If you plan ahead, you won't be disappointed later. — *George Henry Sprague, Jr.*

THE RED AND GREEN FLASHING STAR

"Funny thing about this star," said my husband. "In binoculars, it has flashing red and green lights."

"You're kidding! Let me look." I took the binoculars from him.

Ever since we had the Jacuzzi installed, we have been climbing into it each night with binoculars, star maps, and planetary charts to aid us as we traveled the skies comfortably aboard our tub of bubbling hot water.

"Wonder why I never noticed it before," I said.

"Probably isn't much smog tonight." Our view of the sky is out over the Pacific Ocean facing south about forty-five miles southeast of Los Angeles. A peach-colored finger of smog often stretches out over the ocean from the Los Angeles basin and is visible on the horizon from Laguna Beach.

The star was two fingers above the horizon and would have been visible one finger above the smog, I decided. We use the "finger method" to measure distances on the sky. The idea is to stretch your arm out straight, close one eye, and then count the number of fingers required to cover the distance from one object to another.

Now, as I took the binoculars, I was prepared to find out that my new star was

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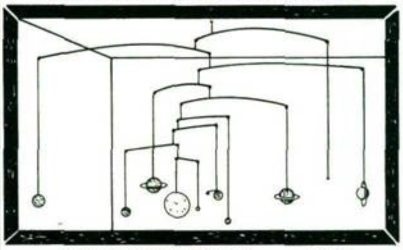

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just an airplane. Sure enough! Red and green lights blinked beside a steady white light.

About ten minutes later I looked again. It was still there! "How do you explain that the airplane is still in the same place?" I asked Bob.

He looked at it again. It looked like a star without binoculars, but with binoculars it looked like an airplane. Could it be a helicopter hovering out over the ocean? That didn't make sense. If it were searching for something, it would move around quickly. It was much too high to be the mast of even a large ship.

The next morning my husband announced that he had solved the mystery. "It has to be some sort of weather balloon tied to a boat. It has to belong to the Navy, the Coast Guard, or the Weather Bureau."

That night it was back. Two fingers above the horizon and one finger from the edge of the building that blocked our view to the east. We tracked it to one finger above the horizon and three hands from the building. This took several hours.

"Did I tell you I called the Weather Bureau, the Coast Guard, and the Harbor Patrol to ask about a weather balloon or something with lights on it?" Bob asked. "No one had heard of it."

It took us a week to notice that the "star" appeared to move with Sirius. That became our way of finding it. We'd look up at Orion, over to Sirius, and down almost to the water. If it was there at all, that's where it was, though none of our Northern Hemisphere star maps showed a star there.

We decided to drive up to Palomar Mountain on Sunday to see if any of the astronomers there could explain what we had seen. After the tour Bob asked the guide, a student at the California Institute of Technology, about the light we saw from our sea-level porch in Laguna Beach.

"What you are seeing is Canopus in the southern constellation Carina, part of *Argo*," said the astronomy student. "Canopus is the second brightest star in the sky, and it is very difficult to see from here.

"However, when conditions are just right, the light from Canopus is bent by Earth's atmosphere and the star appears to be just a couple degrees above the horizon. The red and green flashing lights are the result of the star's light traveling at different speeds through Earth's atmosphere."

"It might be easier to see it from here on the top of the mountain," I suggested.

"Yes," answered the student. "The way a flea has a better look at the Moon when it jumps on a dog's back." — *Beverly Mosier* ☐

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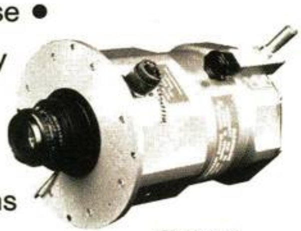

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INTRODUCTION TO THE NIGHT SKY

Discover the Stars by Richard Berry, (Harmony Books, 1987), ISBN 0-517-56529-3, 119 pages, $10.95.

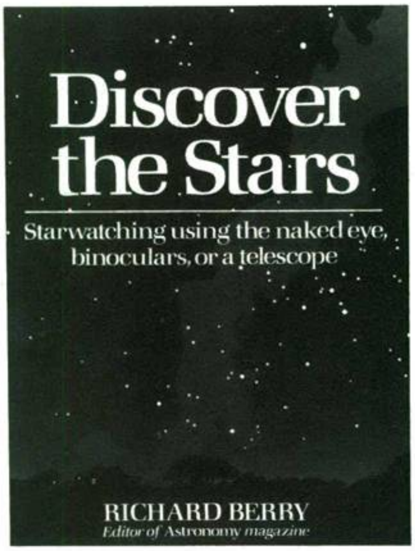
We all have to start somewhere when it comes to learning the night sky, and Richard Berry's book is an ideal beginning. *Discover the Stars* is designed to be "the perfect introduction to the heavens" for anyone who wants to learn the constellations and some objects in the night sky but doesn't know where to begin. The information is presented in an easy-to-grasp, nontechnical manner.

The bulk of *Discover the Stars* consists of star maps and accompanying guide text. The maps are white stars on a sky blue background, which makes them easy to read with low illumination at night. Of the thirty-five star maps, twelve depict just the constellations; a second set of twenty-three charts presents considerably more detail in the way of deep-sky objects and variable and double stars.

In addition to the sky maps the book includes introductory material that orients the observer to sky motions and directions, an overview of the constellations, and how to make an astronomer's flashlight. Brief chapters on observing the Moon and the planets, plus a guide to learning more about astronomy, round out the book.

Those who don't know the constellations will probably turn to the monthly star maps right away. These show you what the naked-eye sky looks like on the 7th of each month at 10 p.m. Because the map for one month is usable during other months, a table tells you which sky map to use on different days at different times.

Each sky map is preceded by a page of text that presents the mythology of the constellations, the importance of constellations to ancient civilizations, and how to locate constellations in that month's sky. One minor yet distracting problem I found with the maps is the unusual way the outline for Orion is shown. Berry has drawn the lines directly from the two bright upper stars (Betelgeuse and Bellatrix) to the two bright lower stars (Rigel and Saiph). All of the star maps and books I have seen show these lines connected to the two outer stars of Orion's belt, and that seems to be how most people perceive the figure. But despite my personal preference for certain constellation lines, I am impressed by how easy the sky maps and sky charts in the book are to use.


Discover the Stars
Starwatching using the naked eye, binoculars, or a telescope
RICHARD BERRY
Editor of Astronomy magazine

To keep the sky maps uncluttered, the author left off such things as star clusters, galaxies, and other deep-sky objects. But do not despair: Hundreds of these objects are shown on the twenty-three star charts that follow the sky maps.

The book is intended for beginners, so right ascension, declination, and universal time are not used in the charts. I think including these would have only confused and frustrated the beginner. To locate stars and deep-sky objects, Berry tells you how to "star hop," a simple and flexible method used by many observers.

The greatest portion of the book is devoted to twenty-three star charts. The charts depict small portions of sky and are accompanied by a page of easy-to-follow text that tells you what objects to look for. Many objects that you can see with binoculars are pointed out as well as those that require 6-inch, 8-inch, or larger telescopes to view.

One feature I really liked was the eyepiece impressions included with each star chart. These illustrations represent what you will see when looking at various objects through binoculars or a telescope. The appendix includes a handy table listing this information so you will not have to thumb through the book to locate the right sky map or star chart to use for any day and time.

Another strong point of the book is the list of all eighty-eight constellations near the back of the book. The list includes each constellation's pronunciation, meaning, abbreviation, prime observing period, and the sky map or star chart the constellation is on.

Overall, I liked *Discover the Stars* and recommend it for anyone interested in learning the basics of astronomy. The information is clear, concise, and covers just about all that a beginner needs to know. — *Robert Garfinkle*

STEPHEN HAWKING'S COSMOLOGICAL TESTAMENT

A Brief History of Time: From the Big Bang to Black Holes by Stephen W. Hawking, (Bantam Books, 1988), ISBN 0-553-05243-8, hardcover, 240 pages, $18.95.

Stephen Hawking's insightful contributions to the Big Bang theory, black holes, and cosmology have inspired many of his colleagues to elevate him to the status of Einstein and Newton.

Yes, you say, but can he write a clear sentence? Can he explain string theories without entangling the reader in cosmo-jargon and indecipherable equations?

Happily the answer is yes. Hawking has written a book that provides the general reader with an overview of key cosmological issues that he and other physicists have been wrestling with for the past few decades. Rather than being stilted and heavy-handed, the content of *A Brief History of Time* is blessedly all the richer and more meaningful because of Hawking's background and experience.

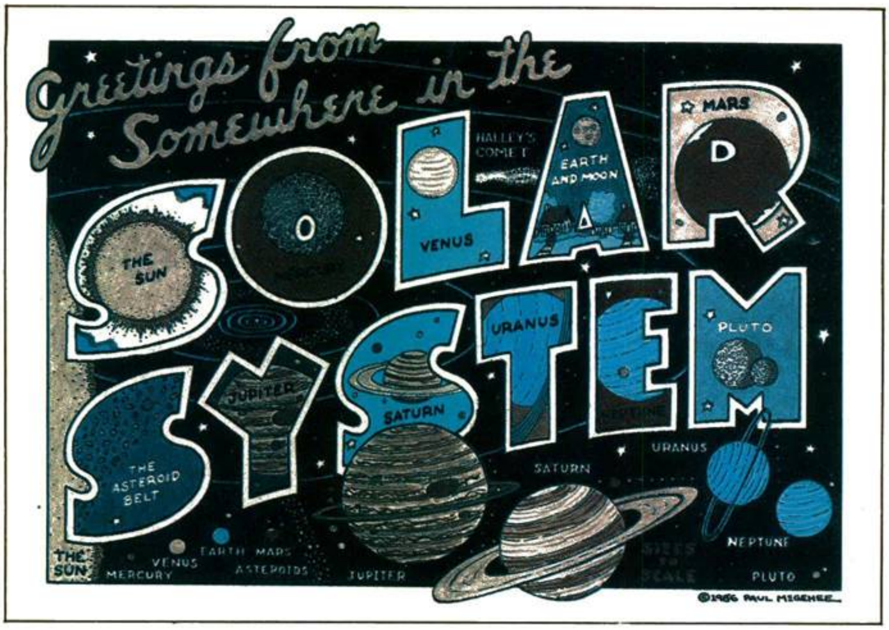
He opens with a historical overview of cosmology from the early Greeks to modern times, which sets the stage for subsequent chapters on the two great theories of twentieth-century physics: relativity and quantum mechanics. Hawking believes physics is close to resolving the differences between these two theories and that the unification will resolve many of the mysteries of the universe.

Chapters follow on black holes, the origin and fate of the universe, the nature of time, and the search for a grand unifying theory of the universe. The last chapter addresses the latest in string theories and multidimensional space.

As weighty as these subjects are, Hawking writes about them with a lightness and clarity that makes this book a pleasure to read. — *Jeff Kanipe*

POSTCARDS FROM THE PLANETS

Greetings from Somewhere in the Solar System by Paul McGehee, (self-published, 1987), $7.50.



Do you recall those crazy postcards from the "tail fin" era of the 1950s — the ones that screamed out the name of some touristy place in colorful big block letters? "A HELLO from FLORIDA! LAND of SUN! SURF! and PINK FLAMINGOS!"

Artist Paul McGehee, his tongue stuck firmly in cheek, has treated the solar system to the same wacky boosterism. The hilarious result is a set of fourteen color postcards printed on heavy stock. "Greetings from MERCURY, the FRIED planet!" "Having a GAS! — Here at JUPITER!" "DOWN is UP on URANUS, the SIDEWAYS planet!" You get the idea.

Because he's had only limited success in getting these things into planetarium and space center gift shops, he sells them mainly by mail. He charges $7.50 for the first set you order (postage included); additional sets ordered at the same time cost $5. Write to P.O. Box 7384, Salem, Oregon 97303.

Anyone who wears his astronomy knowledge like a starched shirt will loathe these things. — *Robert Burnham*

COSMOLOGY

Kepler's Geometrical Cosmology by J. V. Field, (University of Chicago Press, 1988), ISBN 0-226-24823-2, hardcover, 243 pages, $37.50.

Origin and Evolution of the Universe: Evidence for Design?, edited by John M. Robson, (McGill-Queen's University Press, 855 Sherbrooke Street West, Montreal, Quebec, Canada H3A 2T7, 1987), ISBN 0-7735-0618-7, paperback, 297 pages, $15.95.

EQUIPMENT GUIDES

Automated Photoelectric Telescopes: Proceedings of the Seventh Annual Fairborn IAPPP Symposium, edited by Douglas S. Hall, Russell M. Genet, and Betty L. Thurston, (Fairborn Press, P.O. Box 7531, Mesa, AZ 85206, 1986), ISBN 0-911351-08-6, paperback, 182 pages, no price given.

HISTORY

The Collected Papers of Albert Einstein, Volume 1: The Early Years, 1879-1902, English translation, (Princeton University Press, 1987), ISBN 0-691-08475-0, paperback, 196 pages, $22.50.

Elites in Conflict: The Antebellum Clash over the Dudley Observatory by Mary Ann James, (Rutgers University Press, 1987), ISBN 0-8135-1245-X, hardcover, 301 pages, $30.

Galileo: Heretic by Pietro Redondi, (Princeton University Press, 1987), ISBN 0-691-08451-3, hardcover, 356 pages, $29.95.

Voice of the Universe: Building the Jodrell Bank Telescope by Bernard Lovell, revised and updated edition, (Praeger Publishers, 1987), ISBN 0-275-92679-6, paperback, 300 pages, $14.95.

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Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time by Stephen Jay Gould, (Harvard University Press, 1987), ISBN 0-674-89198-8, hardcover, 222 pages, $17.50.

The Nature of Time, edited by Raymond Flood and Michael Lockwood, (Basil Blackwell, 1987), ISBN 0-631-14807-8, hardcover, 187 pages, $19.95.

Time Travel and Other Mathematical Bewilderments by Martin Gardner, (W. H. Freeman, 1988), ISBN 0-7167-1925-8, paperback, 295 pages, price not given.

PHYSICS

Elementary Particles and the Laws of Physics: The 1986 Dirac Memorial Lectures by Richard P. Feynman and Steven Weinberg, (Cambridge University Press, 1987), ISBN 0-521-340004, hardcover, 110 pages, $12.95.

Genesis and Propagation of Cosmic Rays, edited by Maurice M. Shapiro and John P. Wefel, (D. Reidel, 1987), ISBN 90-277-2628-0, hardcover, 476 pages, $94.

How Experiments End by Peter Galison, (University of Chicago Press, 1987), ISBN 0-226-27915-4, paperback, 330 pages, $14.95.

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Looking Back: Amateur Adventures with Halley's Comet, 1985-1986, by David Deskins, (Intrinsic Publishing Corporation, Pikeville, Kentucky, 1987), paperback, 112 pages, $19.95.

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Challenger: The Final Voyage by Richard S. Lewis, (Columbia University Press, 1988), ISBN 0-231-06490-X, hardcover, 249 pages, $29.95.

The Human Quest in Space: 24th Goddard Memorial Symposium, edited by Gerald L. Burdett and Gerald A. Soffen, Science and Technology Series, volume 65, (American Astronautical Society, 1987), ISBN 0-87703-263-7, paperback, 295 pages, $45.

TEXTBOOKS

The Universe and Life: Origins and Evolution by G. Siegfried Kutter, (Jones and Bartlett, 1987), ISBN 0-86720-033-2, hardcover, 529 pages, no price given. ☐

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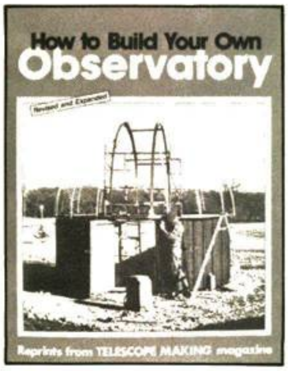

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Meetings and Events

August 2-11
20th General Assembly of the International Astronomical Union, Baltimore Convention Center, Baltimore, Maryland.

August 5-6
Starfest '88, River Place Campground, north of Mount Forest, Ontario. Contact: North York Astronomical Association, 16 Beaufield Avenue, Toronto, Ontario, Canada M4G 3R3.

August 5-6
"War of the Worlds" Mars Symposium, Roper Mountain Science Center, Greenville, South Carolina. Special guests: ALPO Mars Recorders Jeff Beish and Don Parker; observing. Contact: Doug Gegen, Roper Mountain Science Center, 504 Roper Mountain Road, Greenville, SC 29615-4229. Phone: (803) 297-0232.

August 6
Annual OTAA Convention, University of Akron, Akron, Ohio. Sponsored by the Astronomy Club of Akron. Contact: Lauri Kunkel at (216) 762-5748.

August 10-14
5th Annual Mount Kobau Star Party, Okanagan Valley, British Columbia. Contact: Peter Kuzel, 4100 25th Avenue, Vernon, British Columbia, Canada V1T 1P4. Phone: (604) 545-1226.

August 11-13
3rd Annual Sedona-Verde Valley Astrophotography Festival: Perseids, Verde Valley Preserve, Thousand Trails, Inc., Arizona. Contact: Russell A. Nidey, 1101 Zalesky Road, Cottonwood, AZ 86326. Phone: (602) 634-7332.

August 12-13
Southern Minnesota Sky Show, New Ulm, Minnesota. Sponsored by the Minnesota Valley Amateur Astronomers. Contact: Roger Dier, Route 4, Box 15A, New Ulm, MN 56073. Phone: (507) 359-2488.

August 12-14
5th Annual Mountain Astronomers Rendezvous and Star Party, Royal Gorge Park, Canon City, Colorado. Sponsored by the Denver and Southern Colorado astronomical societies. Contact: Jim Zechiel, 1175 Emerson #201, Denver, CO 80218.

Submit announcements at least four months before the date of the meeting or event.

When you write organizations listed in Meetings and Events, include a self-addressed, legal-size envelope with your request for information.

August 12-15
Nova East '88, Fundy National Park, New Brunswick. Contact: Royal Astronomical Society of Canada — Halifax Centre, 1747 Summer Street, Halifax, Nova Scotia, Canada B3A 4J8.

August 13
2nd Astronomy Rendezvous and Conference — 1988, Normal, Illinois. Sponsored by the Twin City Amateur Astronomers. Contact: Kevin Brown, 813 West Oakland Avenue, Bloomington, IL 61701. Phone: (309) 827-6790.

August 13
Stellafane, Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Road, Sudbury, MA 01776.

August 19-20
10th Concours Annuel de Fabricant de Telescope Amateur (Amateur Telescope Makers Competition), 998 Notre-Dame West, Lanoraie, Quebec. Contact: Andre Leroux at (514) 322-2138.

August 19-21
Alberta Star Party, Dinosaur Province Park, Alberta. Hosted by the Royal Astronomical Society of Canada — Edmonton Centre. Contact: George Moores, 2415-107 Street, Edmonton, Alberta, Canada T6J 5N4. Phone: (403) 436-2855.

August 19-21
Star Party, Medicine Hat, Alberta. Contact: Mark Corraini, 68 Cactus Street Southwest, Medicine Hat, Alberta, Canada T1A 7L1. Phone: (403) 526-7795.

August 26-28
"Space for All Nations" Conference, Houston, Texas. Sponsored by Students for the Exploration and Development of Space. Contact: Carlos Perez or Kyle Sprecher, University of Houston — Clear Lake S.E.D.S., 2700 Bay Area Boulevard, Box 198, Houston, TX 77058.

August 27-28
Annual Convention of the Astronomical Association of Northern California, Lawrence Hall of Science, Berkeley, California. Contact: Don Stone, A.A.N.C. President, 731 Camino Ricardo, Moraga, CA 94556-1328. Phone: (415) 376-3007.

September
"Month of Mars," Gastonia, North Carolina. Events held throughout the month. Contact: Larry L. Benfield, Gaston Amateur Astronomers, Schiele Museum and Planetarium, P.O. Box 953, Gastonia, NC 28054. Phone: (704) 825-5341 or (704) 827-5538.

Readings and Resources

Elements (page 18)

The First Three Minutes by Steven Weinberg, (Basic Books, 1977). The classic popular account of the Big Bang and primordial nucleosynthesis.

Searching between the Stars by Lyman Spitzer, Jr., (Yale University Press, 1982). A popular-level account of gas, dust, and heavy elements in the interstellar medium.

Stars, Their Birth, Life, and Death by Iosif S. Shklovskii, (W. H. Freeman, 1978). A detailed semipopular book about how stars form and evolve.

Planet X (page 30)

The Discovery of Neptune by Morton Grosser, (Dover, 1979). A historical account of the discovery of Neptune.

Planets X and Pluto by William Graves Hoyt, (The University of Arizona Press, 1980). A historical account of the discovery of the outer planets and the search for Planet X.

"The Systematic Differences between Planetary Observations and Ephemerides," *Dynamical Astronomy*, edited by Victor Szebehelz and Bela Balazs, (University of Texas Press, 1985). A technical article on the data supporting anomalous motions in the orbits of Uranus and Neptune.

Thinking Telescopes (page 42)

Automatic Photoelectric Telescopes, edited by Hall, Genet, and Thurston, and *New Generation Small Telescopes*, edited by Hayes, Genet, and Genet, (both published by the Fairborn Press, P.O. Box 7531, Mesa, AZ 85206). The technical but exceptionally readable proceedings of the seventh (1985) and eighth (1987) annual Fairborn IAPPP symposiums, respectively.

Autoscope, 1357 North 91st Place, Mesa, AZ 85207. Phone: (602) 986-2828. A small company that specializes in making complete automatic telescope systems, parts for those who want to build their own, and plans and software for systems.

"Rent-a-Star" observations are available from Fairborn Observatory for $2 per observational set of UBV measurements, including comparison and check stars. Contact the observatory at 1357 North 91st Place, Mesa, AZ 85207. Phone: (602) 986-2828.

Charting the Moon (page 71)

Information on the computer program for reducing occultation observations can be obtained by sending a self-addressed, stamped envelope to Ron Dawes, 4438 Bikini Drive, San Antonio, TX 78218.

The International Occultation Timing Association provides graze and asteroid occultation predictions and the "Occultation Newsletter" to members. Annual membership is $15 (overseas $20). Address all inquiries to Homer F. Daboll, IOTA, 6 N 106 White Oak Lane, St. Charles, IL 60174.

Martian Dust Storms (page 76)

Introduction to Observing and Photographing the Solar System by Thomas A. Dobbins, Donald C. Parker, and Charles F. Capen, (Willmann-Bell, Inc., 1988). A general guide to amateur observing with individual chapters devoted to each of the planets.

CREDITS

Cover: NGC 1977 in Orion, the Anglo-Australian Telescope Board; *page 4, top*: illustration by Thomas L. Hunt, *middle*: Roy Gephart (40mm f/1.7 lens, Ektachrome 400 film, 20-minute exposure with camera piggyback on telescope), *bottom*: courtesy of Russell M. Genet, Fairborn Observatory; *page 10*: Sacramento Peak Observatory; *page 12*: Richard Berry; *page 14*: Robert Baillargeon, courtesy of the Royal Ontario Museum; *page 16*: Michael A. Stecker (26mm f/4 lens, hypersensitized Tech Pan film); *pages 19-25*: illustrations by Thomas L. Hunt; *pages 26-27*: courtesy of Jay Anderson, Pacific Weather Centre, Vancouver; *pages 30-31*: reproduction courtesy of Charles T. Kowal and Stillman Drake; *page 31*: Lowell Observatory; *pages 36-37*: P. K. Seidelmann, E. J. Santoro, and K. F. Pulkkinen, reproduced from *Dynamical Astronomy* with the permission of the University of Texas Press; *page 38*: Lick Observatory; *page 39*: Tony Moller, U.S. Naval Observatory; *pages 43-45*: photos courtesy of Russell M. Genet, Fairborn Observatory, telescope schematics courtesy of Autoscope; *page 46, top*: courtesy of Russell M. Genet, Fairborn Observatory, *lower*: Mike DuBose, courtesy of Vanderbilt University, data courtesy of Douglas S. Hall, Vanderbilt University; *page 54*: photo by Max Heinzmann on May 25, 1975, beside Mount Rainer (135mm f/2.8 lens, ISO 160 film, 1/8-second exposure); *page 57*: Mars map courtesy of Jeff Beish; *page 58*: sketches by Jose Olivarez; *pages 64-67*: Robert Burnham; *page 68*: George R. Stephan; *pages 71-73*: photos by Robert Reeves; *page 72*: map by Ron Dawes; *page 76*: sketch by Jeff Beish; *page 77, left*: Howard F. Zeh, *middle*: Jean Dragesco, *row of photos, right*: Lowell Observatory, International Planetary Patrol Program; *page 79*: illustration by Bruce Bond; *page 82*: illustration by Vic Costanzo; *page 86, top*: sketch by Richard Baum (3-inch telescope at 120x), *bottom*: Ernest W. Piini; *page 87*: sketch by Don Parker (16-inch f/6 telescope at 485x and 730x); *page 88*: Kim Zussman (11-inch f/10 SCT, hypersensitized Tech Pan film, 130-minute exposure); *page 90*: illustration by Bryan Peterson.

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FOR SALE OR TRADE – Commodore 64C, 1571 disk drive, Thomson RGB monitor, Seikosha sp-1000vc printer, plus software including *Sky Travel, Geos,* and much, much more. $700 or trade for Bausch & Lomb 4000 PRO with tripod or similar telescope with same quality features. Contact Brenner Dunn, 1713 South Fairfield #1, Las Vegas, NV 89102. Phone (702) 383-0527.

FOR SALE – Meade 2080 LX-3 MSCO, tripod and wedge, dew shield, hand control, electric declination, 8x50 polar view finder. All mint. $950. Contact Jim, 8811 S.W. 192 Terrace, Miami, FL 33157. Phone (305) 252-6578.

FOR SALE – Celestron 30x80 multicoated binoculars with case, straps, and lens caps in original box. Mint condition. Will consider trade or $200. Contact Tom Davis, P.O. Box 3291, Auburn, CA 95603.

FOR SALE – Black C-90 on Albinar photographic tripod. Accessories include hybrid diagonal for 1-1/4" eyepieces, 6x20 finder, lens caps, 30mm Kellner eyepiece, porro prisms, T-ring, T-adaptor, 2x Barlow, and carrying case. All in perfect condition. $400. Contact Gary A. Schulze, 1709 Lindenthal, Highland, IL 62249. Phone (618) 654-4188.

FOR SALE – Celestron SPC8 with Starbrite coatings, dual-axis drive with corrector, 26mm Plossl, 7mm Erfle, 9mm wireless illuminated reticle eyepiece, 6x30 finder, Telrad, and more. Excellent optics! $1,000. Will deliver anywhere in southern California. Call Dan Solan at (714) 828-3036.

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FOR SALE – ASTRONOMY. June 1980 to present. Ninety-three issues with the exception of February 1982, May and October 1985, and September 1987. Excellent condition. $100 plus shipping. Contact Stanley L. Shorb, 219 West Avenue, Hanover, PA 17331. Phone (717) 632-2541.

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FOR TRADE – Space videos and audios from Mercury to the shuttle within the United States. Will trade for same. Contact Kyle King, HC 82, Box 520, Kite, KY 41828.

FOR SALE – Celestron polarizer filter assembly and Unitron 18mm 1" eyepiece. Both for $65. Phone (415) 355-2652.

FOR SALE — Castle Observatory. Four levels on one-acre hill under dark skies. Includes 13.1" telescope; math, science and astronomy library; one bath, kitchen, bedroom, and wicker furnishings. $18,500. Contact Pat Stonehouse, 2001 Birch Drive, Wolverine, MI 49799. Phone (616) 525-8713.

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FOR SALE — Celestron C-90 Astro, fork mount, clock drive and circles, latitude adjustable legs, and case. Takes 1-1/4" accessories. $400. Phone Jim at (305) 252-6578.

ANNOUNCEMENT – The Cheyenne Astronomical Society meets on the fourth Saturday of each month at the Laramie County Library at 1:30 p.m. We have two scheduled monthly star parties, special parties for meteor showers, and a monthly newsletter. The society also goes on frequent field trips. Contact Mike Pittman, 216 U Factor Lane, Cheyenne, WY 82007. Phone (307) 634-2509.

ANNOUNCEMENT – First Annual Milwaukee Spaceweek Conference, sponsored by the Milwaukee Lunar Reclamation Society (chapter National Space Society), will be held on Saturday, July 16, 1988, at the MSOE Library. The theme is "Return to the Moon." $4 in advance. Contact MLRS/RTM, P.O. Box 2102, Milwaukee, WI 53201. Phone Peter at (414) 342-0705.

ANNOUNCEMENT – The Astronomical Society of Kansas City meets on the fourth Saturday of each month. Meetings begin at 7:30 p.m. in room 103 of Royall Hall, located between Rockhill Road and Holmes on 52nd Street at the UMKC campus. For more information contact the ASKC, P.O. Box 400, Blue Springs, MO 64015. Phone Gary Pittman at (816) 228-4238.

ANNOUNCEMENT – The Astronomical Society of the Palm Beaches meets on the first Wednesday of each month at 7:30 p.m. at the South Florida Science Museum in West Palm Beach. Join us for lectures, star parties, and related activities. For information phone the Science Museum at (407) 832-1988 or Lawrence Nadel at (407) 478-0541.

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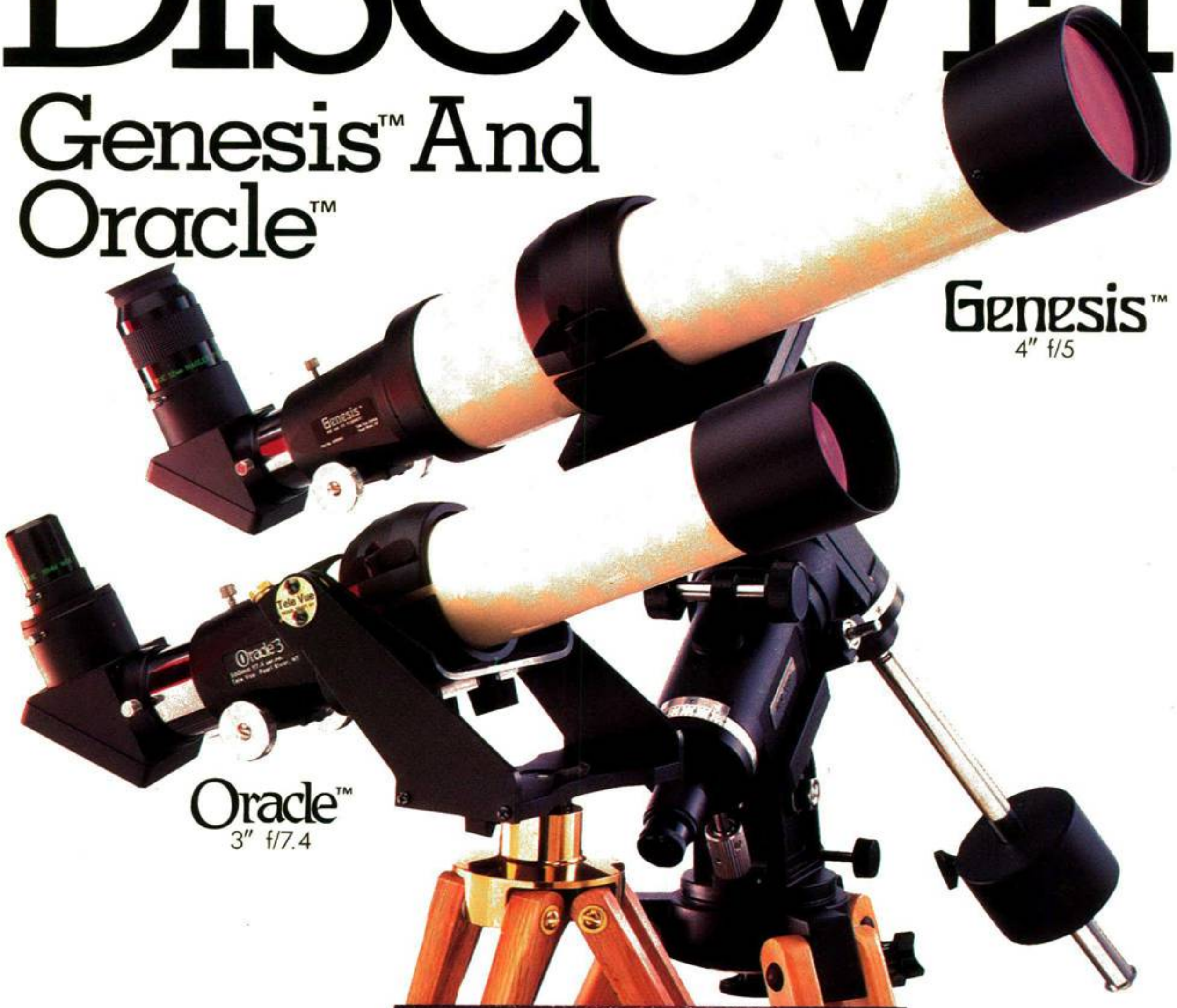

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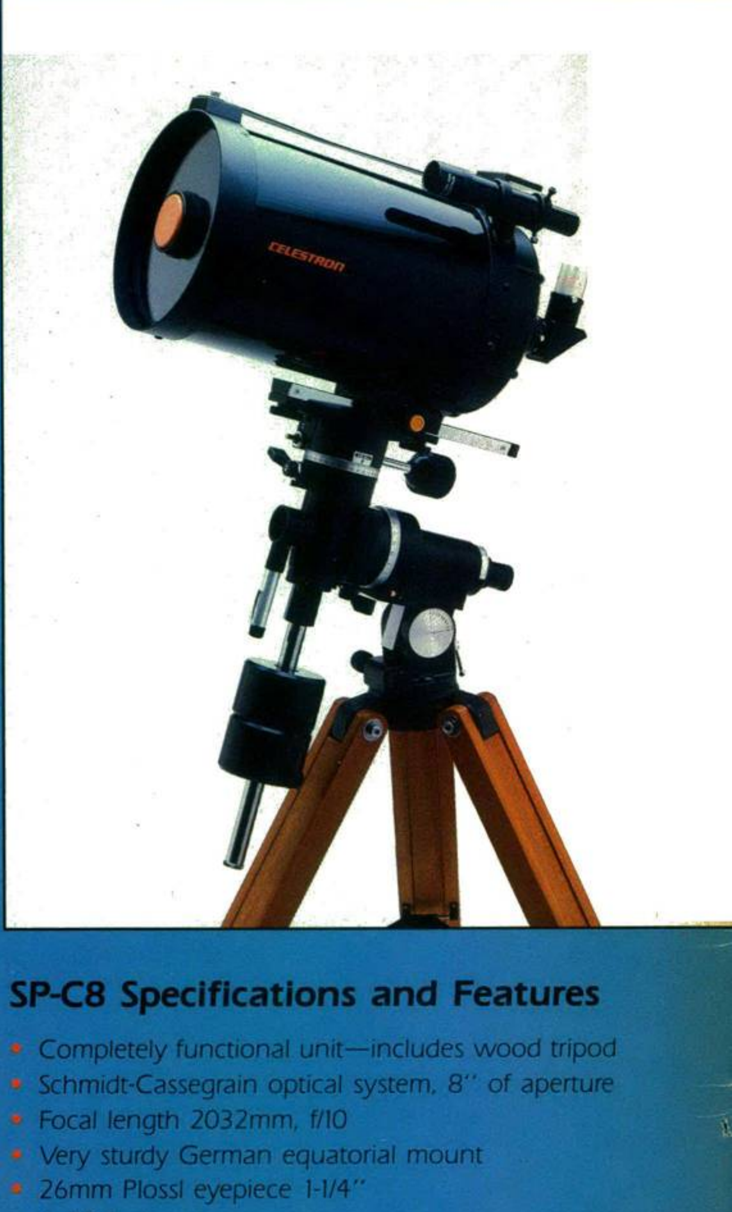

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